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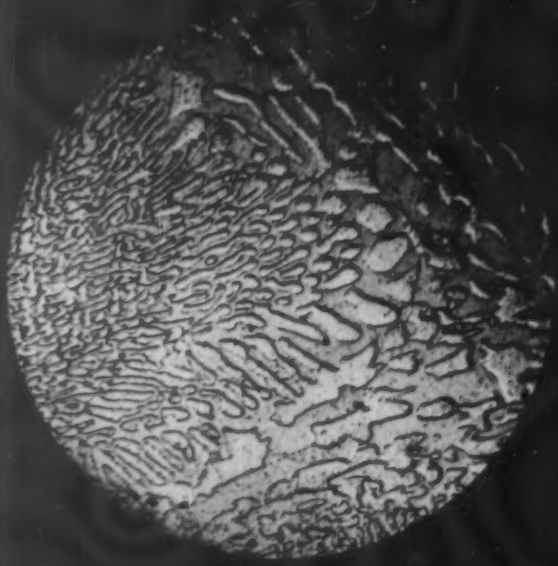
one dollar

IDEAS AND APPLICATIONS

Is a FUNDAMENTAL Research Program Worthwhile?



Normal binary eutectic structure (250X)

New binary eutectic structure (250X)

We, at the Research Laboratories, are convinced that it is worthwhile. For example, one of the fundamental scientific programs being undertaken is a study of the mechanism of solidification of polyphase alloys.

This study is still in its early stages. However, we now have a better understanding of the solidification process. And we have demonstrated that the microstructure of certain eutectics can be significantly altered by controlled solidification. The contrast is illustrated above.

It is possible that these binary alloys with preferred orientation may have unusual physical and mechanical properties.

Perhaps you are interested in corporate–sponsored studies into the fundamental nature of matter. If so, we can offer a research environment that seems to stimulate scientists to extra achievement. It may be due to the way we encourage an internal cross-fertilization of ideas; or because of a unique complex of complementary services that free the scientist from routine analysis and experimental chores.

Opportunities for scientists in the physics of solids, liquids, gases, and plasmas. Current studies range from the fundamental properties of matter to the application of scientific knowledge to promising new products.

• • •

For more specific information, please write to Mr. W. C. Walsh at the Research Laboratories.

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UNITED AIRCRAFT CORPORATION
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UAC RESEARCH

OCT-NOV 1960 **RE**

THE COVER, *illustrating complex man and his ability to receive and use sound, is after a three-dimensional painting by Gertrude Harbart and an earpiece from a portable radio. The cover illustrates this issue's special section on sound – three articles by research leaders in various aspects of sonics and ultrasonics.*

The Industrial Uses of Sound *(p. 45) tells of growing uses of sound for measuring, testing, and processing.* The Laboratory Uses of Sound *(p. 51) shows how sound can be a tool for exploring basic properties of matter.* Life Sounds and Communications *(p. 55) tells how sound can be used to control the animal world, and how animal systems suggest engineering systems.* The Research Trendletter *(p. 69) presents additional recent developments in sound.*

The Mode of Materials Research *(p. 15) suggests that the current emphasis on materials research will pass because materials research is practically the same as all research.*

Two very different views on reliability are offered in this issue. Reliability: an Engineering Problem *(p. 22) tells how to do it, what it is, how to measure it. The reliability manager's place is in the middle of conflicting elements when reliability troubles occur, according to* Reliability: a Management Problem *(p. 28).*

Human-Factors Engineering *(p. 36) gives the background and present state of this expanding art and science. In the past, designers of equipment have selected approaches, materials, and parts according to requirements, but they forgot about the human operator's capabilities.*

Lastly, an article marking the 300th anniversary of the Royal Society is An Optical Method for Dimensional Measurement *(p. 62). Inexpensive diffraction gratings made by this new process are opening up new applications for gratings; an important use is in machine-tool controls, to make accurate gearing and mechanical parts unnecessary.*

VAC **46,000** copies of this issue printed. Circulation audited and verified by Verified Audit Circulation Corp.

Industrial Research is dedicated to reducing the time lag between invention and production. It seeks to do this by informing technical management, creative engineers, and research workers of new scientific developments and their profitable applications in all fields of industry.

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INDUSTRIAL RESEARCH

OCT-NOV 1960

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technical director, **Dr. H. L. Garbarino**

assistant editor, **M. E. Aisanich**

news editor, **Walter Esse**

photographer, **Jon R. Pownall**

technical consultants, **Dr. R. W. Benson**
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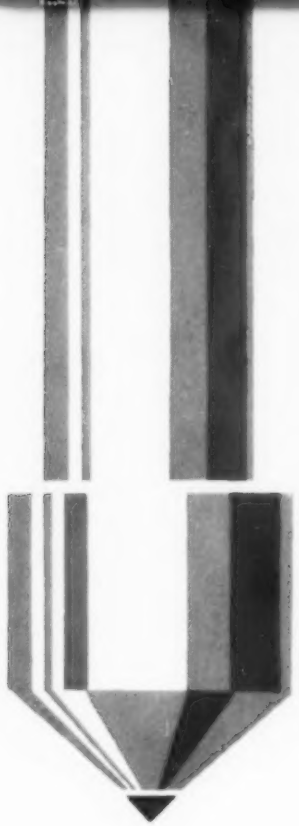
Diamond-impregnated tool



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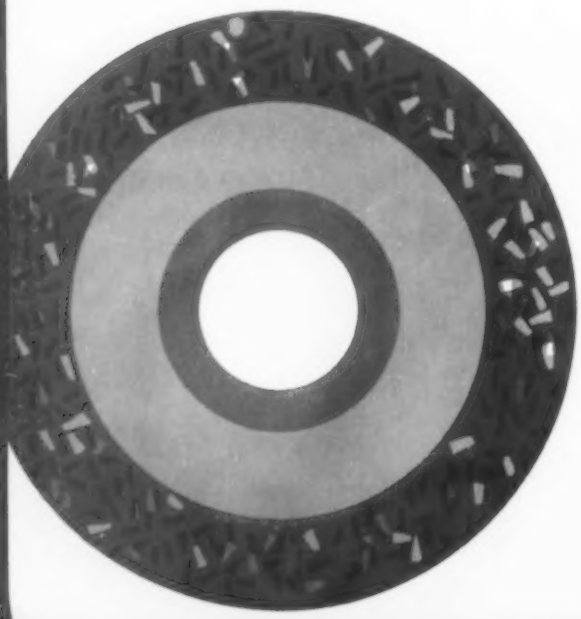
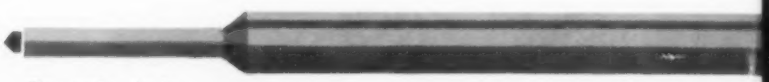
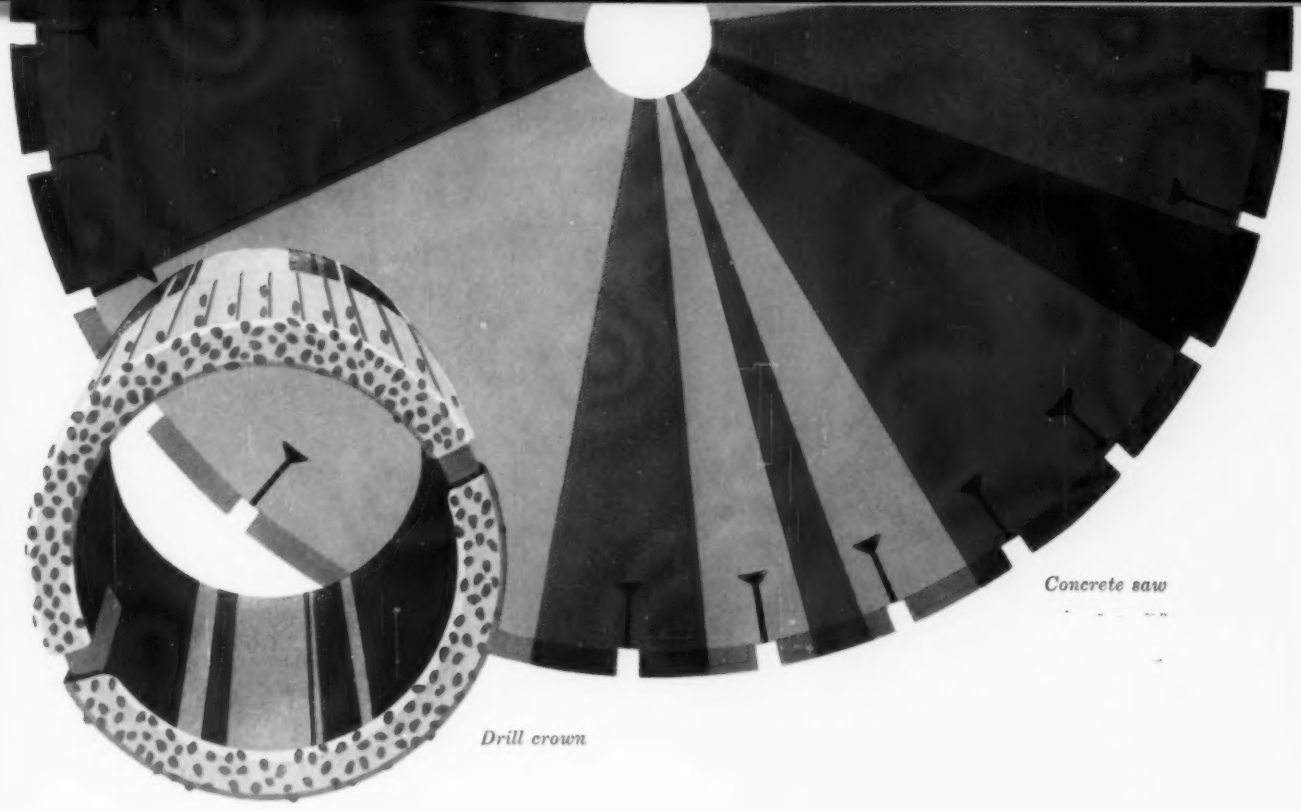


Grinding wheel



Engraving tool

Centering drill



Concrete saw

Drill crown

Just how inexpensive diamonds can be for you, depends on the job you're doing. You'll have to try them to know. The biggest companies in the country, the ones that watch costs most closely, use industrial diamonds consistently.

Next time you buy tools or wheels, try diamonds. Pit them against the cutting method you are now using. Chances are you'll find out how economical a diamond can be.

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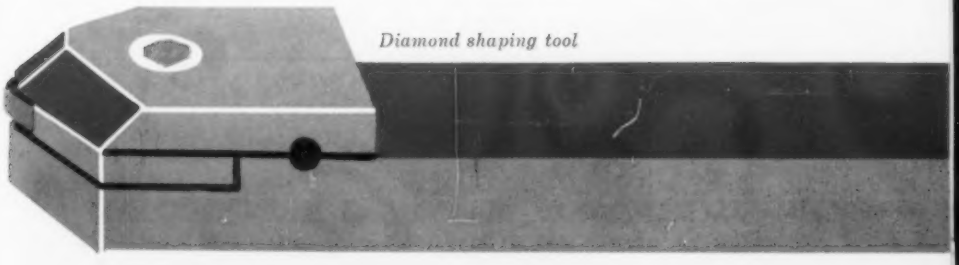

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IR FEEDBACK *from readers*

Miniaturization

Sir:

I have just read your most interesting article on miniaturization in *Industrial Research*. It was of special interest because we are considering the initiation of a project to develop electrically powered artificial arms, and it proved helpful to know which firms are active in the field of miniaturization.

The real problem is not designing such a unit, but in controlling the device without conscious thought. I was especially interested in your statement that groups at GE are studying the basic human electronic mechanisms that stimulate muscles.

A. Bennett Wilson Jr.
Staff Engineer
National Academy of Sciences
National Research Council
Washington, D. C.

Sir:

One of the most interesting aspects of your miniaturization article is the utilization of missile- and space-age research in the industrial world. I have been disturbed by the lack of material comparable to Mr. Berland's article. We are much too intent on defense requirements while overlooking, almost entirely, the needs of our industrial economy.

Unless more information regarding advanced research is placed in the hands of engineers, management, and those responsible for product design as to techniques, components, and materials that can be utilized in our industrial and military efforts, much of value being produced today in R & D laboratories will be lost.

I appreciate the amount of space which your publication has committed to this proposition. However, a far greater effort must be made if we are successfully to transfer the fruits of labor of our research scientists into concrete day-to-day living benefits.

It is my hope that within the next year there will be a concerted movement to develop an organization for promoting industrial applications of military-based discoveries. I will be most happy to assist in any way I can in moving this program forward, and I ask those of similar bent to contact me.

Hal Borgen
Sales Manager–Components
Lumen Inc.
Joliet, Ill.

Rare earths

Sir:

I have a small venture going, with oil leases in Arizona and Utah, and minerals on the side. I am very much interested in the space-age minerals, of which there are many in Colorado, such as gadolinium, yttrium, and other rare earths. I was particularly interested in the article by Dr. Vickery about the rare earths.

Bruce M. Ash
A.A.A. Oil & Minerals Co.
Denver

New-Product Pitfalls

Sir:

I was impressed by the article, "Pitfalls of New-Product Development," in your August-September issue.

George R. Sommers
President
Chico General Products Corp.
Burlingame, Calif.

Sir:

We particularly liked the article, "Pitfalls of New-Product Development."

C. H. Jensen
Supervisor, Quality Control,
Industrial Insulations Division
Johns-Manville Products Corp.
Waukegan, Ill.

Technical motivation

Sir:

Enjoyed reading your "What Motivates the Technical Man?" (June-July issue).

Leo C. Murphy Jr.
Manager, Data Systems Marketing
International Telephone & Telegraph Corp.
New York City

Sir:

Although my own vote would agree with the 87% in your survey who felt that management offered more opportunities than engineering work, I would like to point out that the cards may unwittingly have been stacked in that direction, by reason of the fact that 75% of those participating already were rather deeply involved in the management function. Perhaps more detailed information would prove this to be untrue.

In any event, the results are interesting and do set a pattern.

Robert G. Settelmaier
Assistant Editor
Instrument Society of America Journal
Pittsburgh

Sound and tin

Sir:

You might be interested in a rather unusual and fascinating aspect of sound we have been studying. For many years it has been known that tin, when stressed, emits audible sounds. This came to be known as "tin cry" and was associated with the twinning process [slippage along preferred, parallel, crystalline planes] in tin. Other metals also were observed in later years to exhibit the acoustic phenomenon, i.e., cadmium, zinc, and magnesium. All of these metals readily twin.

Knowledge of this phenomenon led a German scientist to investigate other metals, particularly those that normally do not twin mechanically: aluminum, copper, brass, lead, and iron. Using a piezoelectric transducer and a high-gain amplifier, he found they also exhibited the acoustic emission phenomenon, but at such low energy levels as to be inaudible.

Work at Lessells & Associates has been concentrated on test specimens of single crystals of aluminum and zinc. Piezoelectric transducers mounted on the specimens pick up the sound vibrations induced in the metal as it is stressed in tension. These sounds are amplified and recorded for analysis. Orientations of the crystal axes are varied to study effects on emission characteristics. Data obtained indicates that this acoustic phenomenon is related to fundamental deformation processes occurring at the atomic level or to dislocation behavior.

(continued on page 10)

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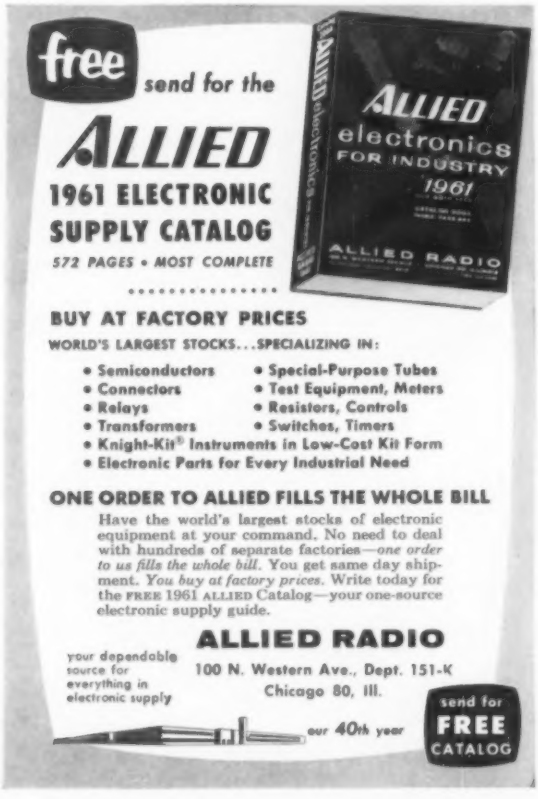
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Future work is to be directed toward studying effects on the acoustic emission phenomenon of temperature, neutron irradiation, and magnetic fields.

B. H. Schofield
Senior Project Engineer
Lessels & Associates Inc.
Boston

The technical entrepreneur

Sir:

I found your article, "The Technical Entrepreneur," extremely interesting.

Stuart H. Rider
Assistant Director of Research
Monsanto Chemical Co.
Plastics Div.
Springfield, Mass.

Borg-Warner research

Sir:

I have just read with great interest the fine article on the Borg-Warner Research Center in your August-September issue.

R. B. Rumely
Food Machinery & Chemical Corp.
New York City

Sir:

I received my first copy of your magazine and enjoyed reading the articles very much, especially those on the rare earths and the description of the Borg-Warner Research Laboratories.

I feel that your magazine provides a useful addition to the general education of the research and/or engineer scientist.

My congratulations on this fine contribution.

John T. Blake
Manager, Systems Engineering Dept.
Atlas Program Office
Space Technology Labs. Inc.
Los Angeles

General feedback

Sir:

I find *Industrial Research* a very interesting magazine, better illustrated and edited than many other technical magazines which I read regularly.

Dr. P. A. Abetti
Manager, Extra-High-Voltage Project
General Electric Co.
Pittsfield, Mass.

Sir:

Your layout or art director does a fantastic job, terrific in fact. Keep up the good work.

Charles A. Notz Jr.
President
Notz & Associates
Crystal Lake, Ill.

Sir:

I can't hold out any longer. I must subscribe to your magazine. I've had the pleasure of seeing a copy off and on and have been very impressed by its quality. Although I now subscribe to 23 other publications, I feel the need of yours.

P. Wright
Indianapolis, Ind.

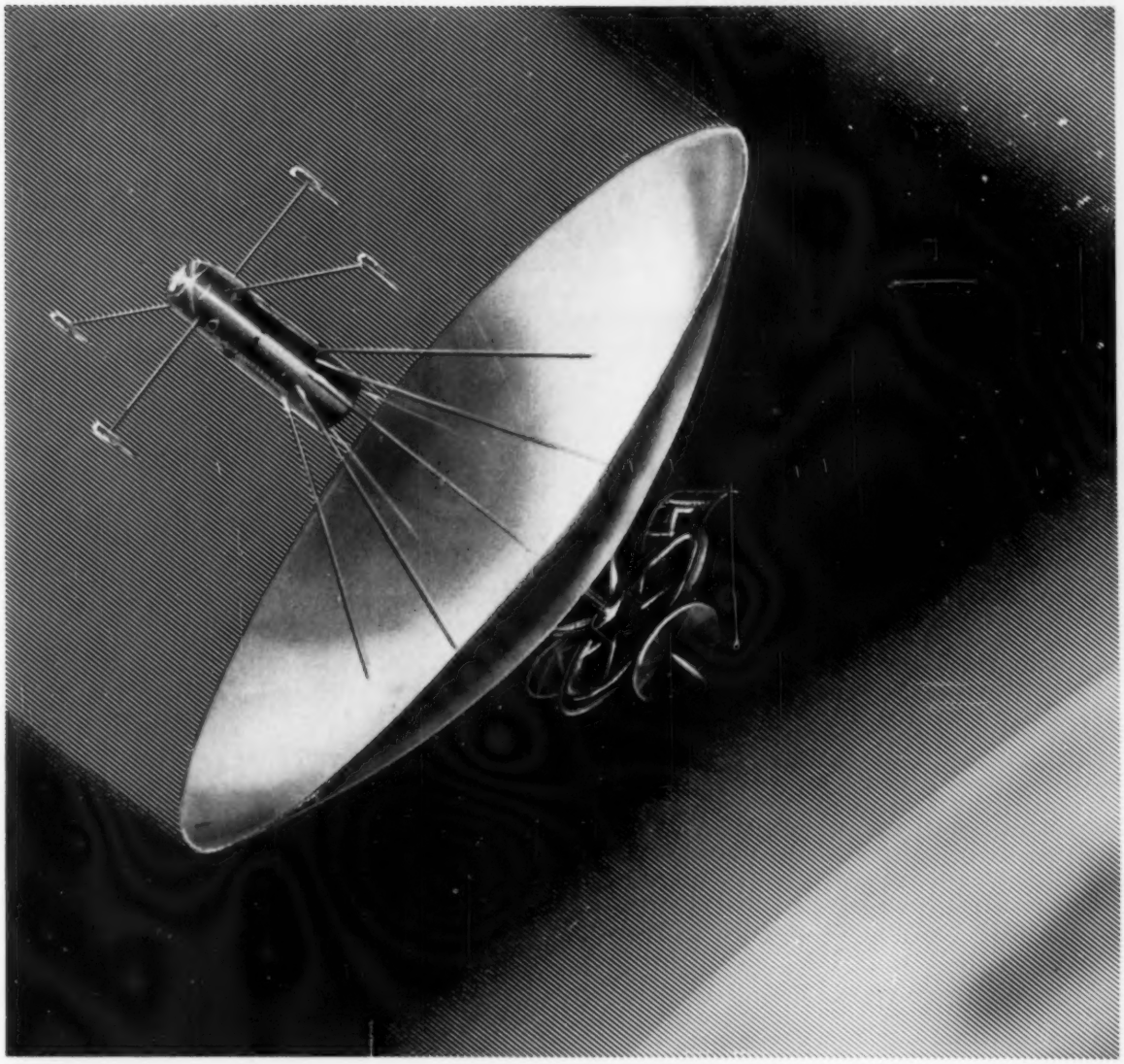
Sir:

The June-July issue of *Industrial Research* (Instrumentation and Control special edition) is a very interesting and informative one.

John A. Ballard Jr.
Veterans Administration Hospital
Syracuse, N. Y.

NO. 32 IN A SERIES

OUT OF THE LABORATORY



Advanced power conversion systems for space vehicles utilizing energy of the sun or heat from a nuclear reactor are now being developed by Garrett's AiResearch divisions. Under evaluation are dynamic and static systems which convert heat into a continuous electrical power supply for space flight missions of extended duration. Component and material developments for these systems are being advanced in the fields of liquid metals, heat transfer, nonmechanical and turboelectric energy conversion, turbomachinery, alternators, and controls — vital contributions by Garrett to the conquest of space.

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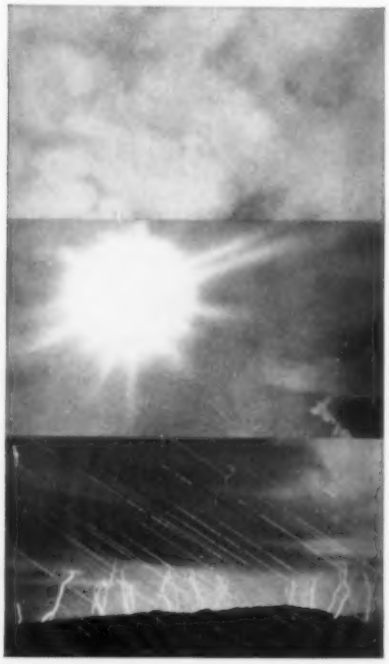

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Westinghouse Electronic Tube Division, Elmira, N.Y.

SELF-COATING *ceramic, graphite-base material, developed at Boeing, is being tested in 2,600F oxy-acetylene blast. Material has promise for coating hypersonic missiles.*

the mode of MATERIALS RESEARCH

by **Dr. A. B. Kinzel,** *vice-president–research, Union Carbide Corp.*

A leading research metallurgist, Augustus B. Kinzel pioneered in the theory of stainless steel, low-alloy steels, and new ferro-alloys. He headed research leading to a process for making titanium, and holds more than 40 patents. Joining Union Carbide in 1926, Dr. Kinzel became chief metallurgist in 1931, and became vice-president for research in 1955. He was educated at MIT and the University of Nancy in France, where he received doctorates in metallurgy and science. He has received honorary degrees and numerous awards for his contributions. Dr. Kinzel has served as consultant to the AEC, and during WW II, he was an advisor on technical intelligence activities in Europe

THE WORLD OF SCIENCE and engineering is supposed to be truly logical and therefore free from passing fads and fashions. We who live in that world know that such is not the case. "Sputniks" and the like have emphasized one part of our technical world, a part which has become so fashionable that, as the saying goes, everybody and his brother is climbing on board.

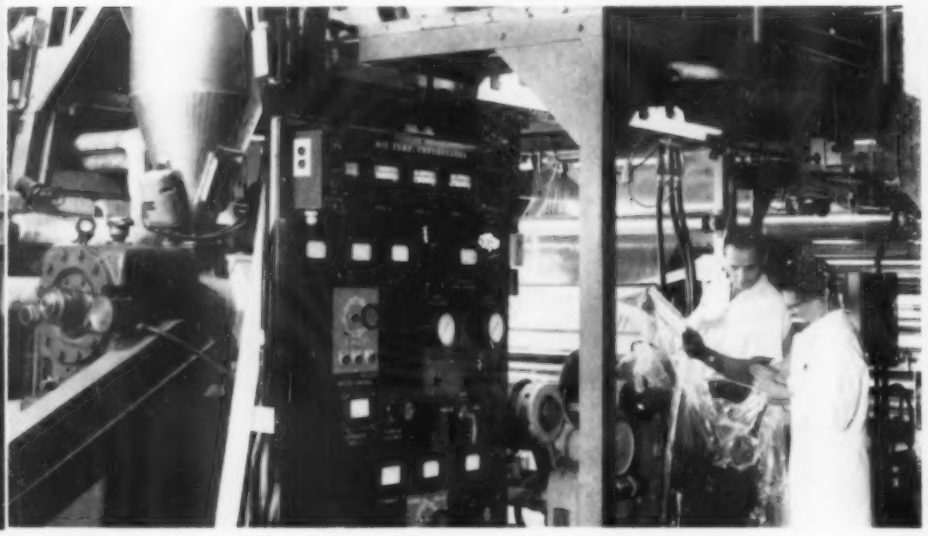
There is, however, one major difference between a fashion in the world of engineering and one in the world of the couturier. In the latter, when the fashion has passed, it is dead. The only lasting effect, aside from pleasure to a few individuals and profit to a few others, is that a base has been set for a resurrection of the fashion in the next generation. In the engineering world the story is different. When the fashion passes, much good has been accomplished. The subject matter finds its normal place in our activities and progress continues for the good of all concerned. The subject finally takes on its proper proportion in our affairs.

Today, materials research is the fashion. It is not new; only the emphasis on it is new. From time immemorial, design engineers have been limited by materials of construction. James Watt had to use cast-iron cylinders for his first steam engine. Thomas Edison had to use a carbon filament for his first incandescent lamp. During World War II our radar people had to use silicon with such impurities as might occur rather than super-pure silicon with foreign atoms intentionally added. In each case the application led to research and development and resulted in different and much improved materials.

Scientists replace engineers

Until the days of WW II, the design of structures, including buildings, mechanical and electrical machinery, and other units of construction, was carried out primarily by the engineer. His first concern was reliability, and believing that reliability could be assured only by experience, he took the best materials available with which he was familiar. Progress was steady and, in terms of today's thinking, slow.

With WW II came the pressure for speed-up in application. Many designs were the work of scientists rather than engineers. Scientists had a different approach. They believed if enough of the facts regarding basic properties of materials were known, reliability could be estimated. Experience was secondary. There just



REACTIONS OF MATERIALS *at high pressures and temperatures are studied in a bomb, which is being assembled at left. Below, special pilot-plant equipment is being developed at Union Carbide for the continuous processing of novel polymeric materials. In the past decade, much has been learned about the molecular architecture of materials, giving impetus to new discoveries.*

Materials research is almost as broad as all research in the physic

wasn't enough time to acquire it.

Moreover, these scientists came from fields of endeavor in which innovation was rampant. They realized that if a material of certain properties required for a design did not exist, it might be possible to produce it in the laboratory. The art of synthesizing materials was rapidly becoming a science and they simply assumed that this science could and should be put to work to meet their purpose.

Quantity is an incentive

With this new approach to materials has come a drastic shift in the source of economic incentives. The material producer's view always had been that new materials should be of such character and price that they would provide a profitable market. With tonnage materials, such as stainless steel or polyethylene plastics, the incentive to synthesize new varieties and continuously improve the old has not changed.

But where "specialties" are concerned—in which total annual quantities are measured only in pounds or even thousands of pounds—the producer's incentive to develop new materials and improve old materials may well be lacking. It costs almost as much to develop production methods for reliably uniform materials in small quantities as it does to provide them in tons. Therefore, the burden of providing an incentive for the producer rests squarely on those who want the improved materials for their specific applications.

In many instances, incentive is provided by a scientist's need to know, a military goal, or a peacetime requirement. Examples are the needs of the National Aeronautics and Space Administration, or of cancer research physicians. Whatever the source, incentive must be sufficient to warrant a producer's effort.

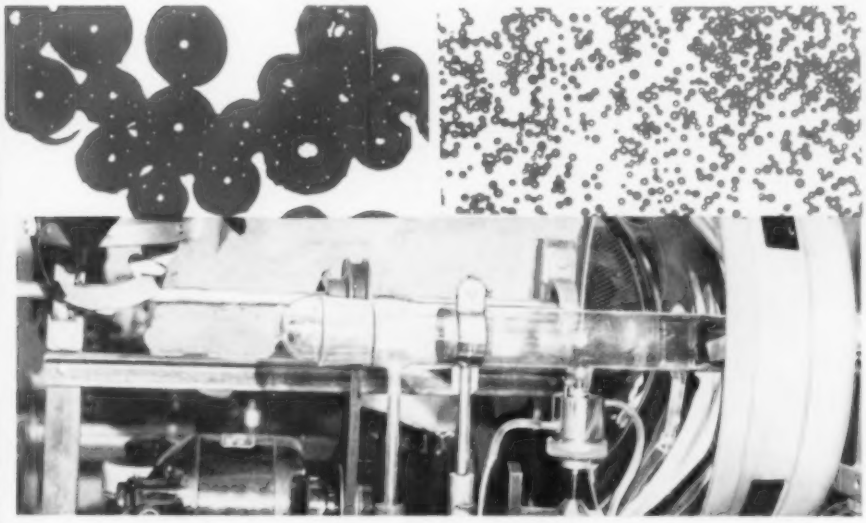
Occasionally, after an initial incentive has been provided by the government, industry will see its way to pick up the ball. Transistor materials are a case in point. The basic research was done by industry; the government then helped by providing the incentive for the development. Then industry—seeing an interesting goal—went ahead on its own.

In providing such goals and incentives, the government should be careful not to overrate them, as in the case of titanium. Here it was government's avowed purpose to stimulate industry and provide another major tonnage metal. When this was done, it was discovered that production facilities were far in excess of demand.

Hindsight is easy and one should not be overly critical of such a situation. However, the fact remains that the abrupt curtailment of government support of the titanium industry resulted in important economic dislocations.

It should be stressed that successful materials benefit not only the original sponsor but all industry and all mankind. Although the initiative for the transistor was undertaken by a single company, the Bell Telephone Laboratories, the transistor has benefited practically every company in the electrical equipment, appliance, and communications fields. In addition, consumers are benefited by better radios and televisions, and we can look forward to still further improvement in our everyday electrical gadgets. New materials always lend themselves to wide exploitation. They are the stuff

SPHERICAL POWDERS *of tungsten, shown below, left and right, may be used to make sintered parts requiring controlled porosity, such as filters, burner plates, nozzles, and piston rings. Arc-image furnace, bottom, is used for studying properties of materials at high temperatures. New high-density graphites, and other refractory materials are being made in laboratories.*



al sciences, rather than a thing unto itself.

that feeds our growing standard of living.

Designing the molecule

In the past decade much has been learned about the molecular architecture of materials and particularly the nature of molecular forces, which may be likened to rubber bands holding the atomic building blocks together. These concepts are basic to all materials, whether synthetic organic chemicals, organic or inorganic crystals, polymers, or metals.

The laws that govern are universal, although constants and parameters may vary in order of magnitude. Today the phrase "science of materials" is used to encompass this body of knowledge and its application has been termed "materials engineering."

In the past, materials science was identified as such only in the more important industrial laboratories dealing with production of materials. It is not strange that most of the important new materials and associated processes of the postwar period have come from these laboratories.

Widespread recognition of such concepts today has been partly responsible for the popularity and attention that materials science has been getting. More than one university or technological institute is moving to establish special departments in materials sciences and materials engineering, and we even hear plans for materials research centers.

What is materials research?

Materials research encompasses a wide variety of disciplines. It requires a true marriage of physics and chemistry. This means not just the merging of one into the other, as in nuclear science, but also a true parallel functioning of the basic physics and the basic chemistry that applies to all materials. Practically every first-class industrial laboratory has men trained in the wide variety of disciplines required. Moreover in such a laboratory, the technique of organizing research teams has been well developed and it is a relatively simple matter to bring the efforts of a well-organized team to bear on the materials problems.

While it is true that the make-up of any team varies with the nature of the problem itself, the general structure is the same and it takes only an individual "sparkplug" member to make it successful. This is true whether the research is fundamental or directed toward immediate application.

Materials research may be broken down into several phases. One problem is providing a new material with specific properties. Another is learning how to produce, in moderate quantities, a known material previously produced only in grams or milligrams. Finally, or first if you will, there is the problem of achieving greater understanding of the relation between the properties and the molecular structure of metal crystals and polymers as well as true compounds. Indeed for the first time do we know enough to ask, "where does one cease and the other begin?"

Motivating research

Research may be motivated by requirements for a new material or by the knowledge that a new material can be produced as a result of a new fundamental finding. To reach into history for an illustration, during WW II the Germans invented a high-strength aluminum, and Paul Merica, then of the U. S. Bureau of Standards, did his noble work on precipitation as a means of strengthening metals, including a theory that in essence still holds.

M. G. Corson was the first from a practical point of view to appreciate the implications of this technique for other metals. By extending the theory to copper and by using knowledge concerning solubilities of other metals in copper, he designed experiments that produced a series of precipitation-hardened alloys known as the Tempalloys, the first truly hardenable coppers.

The same approach has been used since to provide increased strength in a wide variety of metals including most recently, the precipitation-hardened austenitic stainless steels.

Let's now look at what has happened since WW II in materials science and engineering. Work in industrial laboratories, and to a lesser extent in universities and nonprofit research institutes, has resulted in a whole catalog of new materials available for the design engineer. These include, in addition to laboratory curiosities, elements in adequate quantity, materials of a purity previously unthought of, new compounds and new atomic or molecular arrangements in crystals or

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polymers, and finally new processes to provide all of these materials.

Materials have to keep up

The need for new materials was prompted by engineering requirements to implement scientific advances. For example, in the field of atomics a new criterion for materials was added, neutron absorption. Many materials in common use failed to meet this criterion. As a result, industrial research has resulted in vanadium metal, both columbium metal and columbium alloys resistant to oxidation, boron steels for control rods, and special types of graphite for moderators.

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We have a whole new spectrum of pure rare earths, primarily the result of the work of Spedding at Iowa State University. While uranium and hydrogen-bomb requirements as well as fission power reactor requirements have put a heavy demand on the metals industry, there is as yet no equivalent demand for materials related to the problem of controlled fusion. Temperatures involved here are so high that we have not been able even to conceive of any useful material. The problem has been tackled following a variety of schemes, but in common, they would confine the fusion reaction in a container of its own plasma.

Rocketry probably places more demands on materials than any other engineering pursuit. First are the fuels—ranging from liquid hydrogen which industry has made available now in tank-car lots, through the higher-energy organics, to the so-called exotic fuels based on organic or inorganic metal compounds. In this connection, the new insulating materials for use at temperatures approaching absolute zero should also be cited. Then there are the solid fuels that require not only those elements or compounds that provide the specific thrust, but also a polymeric carrier. This may or may not be a high-energy combustant, but it must have a variety of other properties relating to burning rate, thermal shock, expansion stress and adhesion.

A second problem of materials for rocketry is achieving reliability of the electrical control components, particularly connections and insulation. This really boils down to using materials that will permit the elimination of as many connections as possible in the circuitry and using materials that will combine potting and insulating. (Potting means encompassing the entire circuit in a suitable plastic mass.)

Here the new processing, such as vapor deposition and other methods of providing printed or analogous circuitry sets up one of the materials problems and the nature of the potting material sets up the other. The new silicones and the deposition of material from carbonyls, halides, and complex metal organic compounds have helped provide solutions to the materials problems, but much remains to be done.

The problem of ablation also presents a materials problem in which the basic mechanisms are still not too well understood. Certain plastics are providing a reasonably satisfactory solution, but, again, the real work is ahead of us.

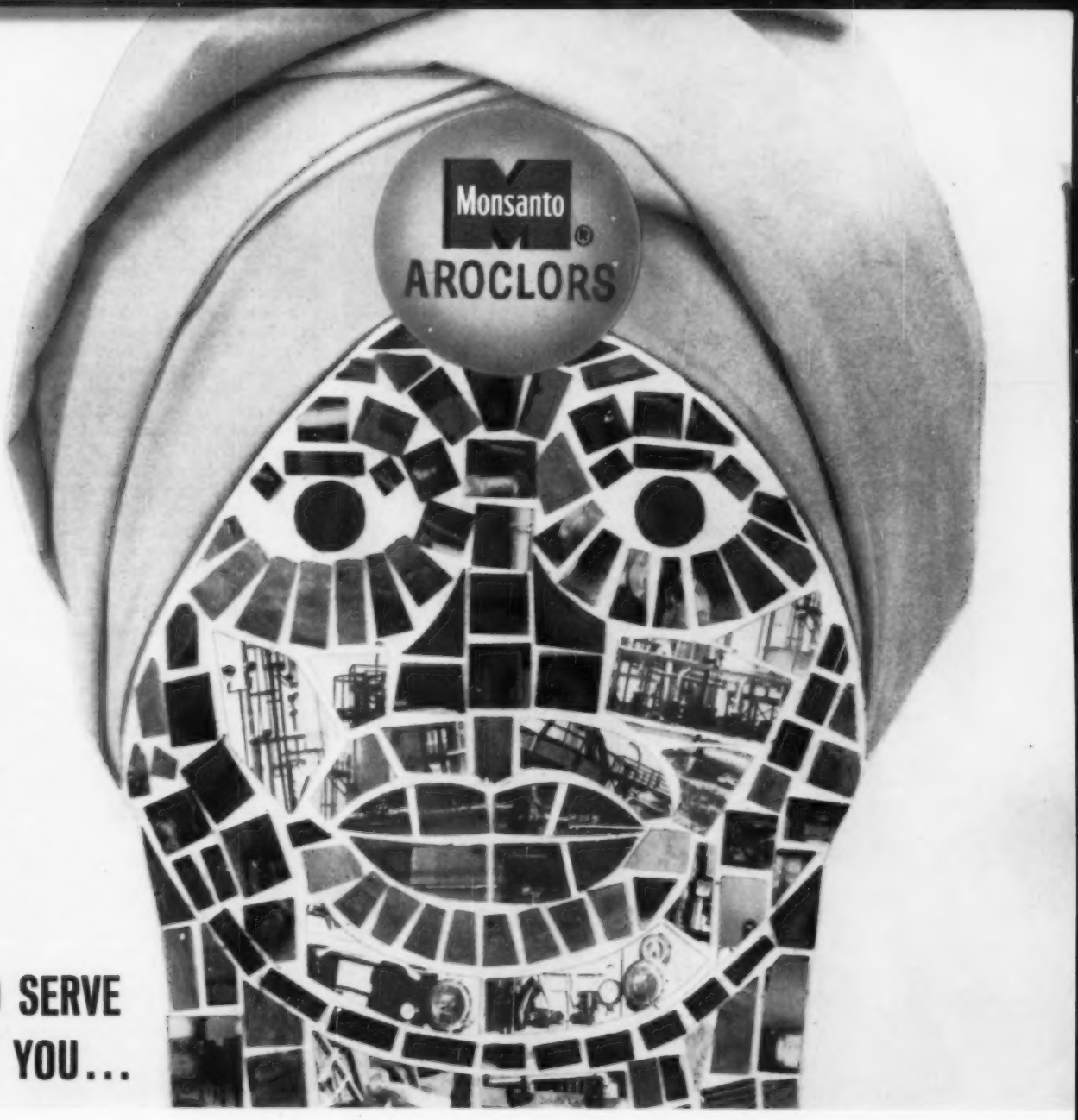
High-temperature materials

Most high-temperature problems are linked to the requirements of rocketry and jets. New high-density graphites, silicon nitride, various intermetallics and refractory materials, such as silicides, borides, and carbides, have been produced in a number of laboratories, both industrial and nonprofit, mostly on a small scale. The methods used in most cases are suitable for large-scale production when the demand warrants.

In this area, sapphires should be mentioned in that their special property of transparency to certain electromagnetic wave lengths, as well as infrared, makes them particularly useful. One of the recent achievements has been production of sapphire articles in relatively large shapes such as discs and domes.

Coatings of highly refractory materials are of particular interest, and new methods for applying these coatings have been developed. Spray guns incorporating a high-temperature flame or high-density arc are used for spray coating with refractory materials such as alumina and tungsten carbide, with few limitations regarding material to be sprayed. Vapor deposition, by means of high-temperature dissociation of metal compounds, generally in vacuum or at very low pressure, is also a means of providing coatings and promises to be particularly useful when closely defined, limited areas are to be coated.

In the jet field, turbine materials probably receive the most attention. As yet blading is essentially metallic but blade temperatures are becoming ever higher and higher as the science of alloying to get both



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corrosion resistance and strength at high temperature is being applied progressively to base materials of higher melting compounds or greater intrinsic high-temperature strength. Stainless and nickel-base alloys are being supplemented by cobalt-base alloys, and these in turn will be supplemented by columbium-base materials.

Moreover, while metallurgists cannot yet see their way to using tungsten and molybdenum-base alloys having the requisite qualities, these alloys have great potential promise. As the science of materials progresses, we can look for realization of that promise.

Before leaving the subject of high temperature and pressure, one must include the synthetic diamond among the achievements of the last decade. Although it is not a structural material, it has a real place in our industrial complex. One should also mention shock-resistant glass, another industrial materials success.

The impact of plastics

Probably no single field has shown as much postwar progress or has had a greater impact on everyday life than that of plastics. Silicones already have been mentioned. Polyethylenes, best known to the public in the form of squeeze bottles, have had remarkable acceptance. But low-density polyethylene is only the first of a whole series of polyolefins, and the high-density rigid polyethylene, now finding a major place in commercial application, is being supplemented by other polyolefins.

Elastomeric foams have found a major place in industry and these are being supplemented by rigid foams. Here we have not only the well known polyvinyl and polyurethane types but also many others ready for commercial use as requirements for particular properties develop. And several new classes of polymers are already well over the horizon. The best known of these are the epoxys, with the phenoxys beginning to loom large.

In fact, the whole science of producing copolymers is growing at a rapid rate and there seems to be no end to the specific sets of properties that can be produced. Films, a special form of plastic, are being tailor-made with special properties such as resistance to diffusion of moisture and oxygen, clarity, and shrinkability. The promise of even better tailoring is at hand. The art of cross-linking molecular chains, either thermally or by means of radiation, rapidly is becoming a sci-

ence and promises still further modification of the properties of polymers.

This leads directly into the story of fibers. Not only do we have superior synthetic textile fibers among the organic polymers, but glass fibers also have become common in the last decade and metal fibers are beginning to enter the field. From organic chemistry, new solvents, new base materials for making plastics, and new means of forming and reforming petro-chemical products are being developed constantly. New products encompass metal organics as well. The latter are best known as materials which provide antiknock properties, but many other new applications are developing.

The pharmaceutical industry would be almost unrecognizable to one who had not viewed it since the early days of WW II. Synthetic antibiotics, hormones, and tranquilizers are common.

Synthetic chemistry promises to play a major role in the control of cancer. The science of molecular architecture is hard at work to provide compounds having the specific molecular structure necessary to control cancer without undesirable toxic side-effects. New hypotheses are being advanced and new chemicals are being synthesized to test these hypotheses.

Materials research vs. research

One could go on and on and the list will go on and on as research provides ever better things, but there is an important generalization from all the foregoing. The science of materials embraces chemistry and biochemistry, polymerics, cryogenics, physics, mathematics, metallurgy, and even geology. Indeed, so many fields of science are involved that we are forced to the generalization that the science of materials is a horizontal slice through the whole matrix of science rather than the vertical slice of a specific discipline.

Thus we must conclude that the science of materials is a misnomer and that materials research is almost as broad as all research in the physical sciences rather than a thing unto itself. The emphasis should be on more research rather than on more materials research. This will occur when the fad and fashion passes and materials research and materials engineering once again find a proper place as one important approach to better living rather than as a new scientific discipline. In the meantime, much good will have been accomplished. ■

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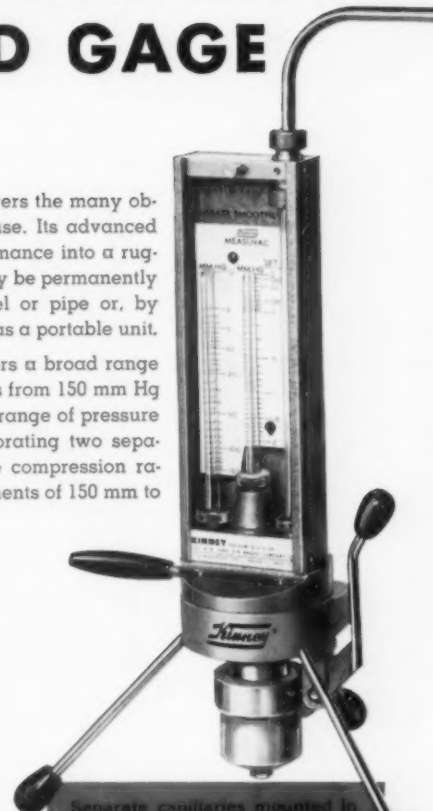

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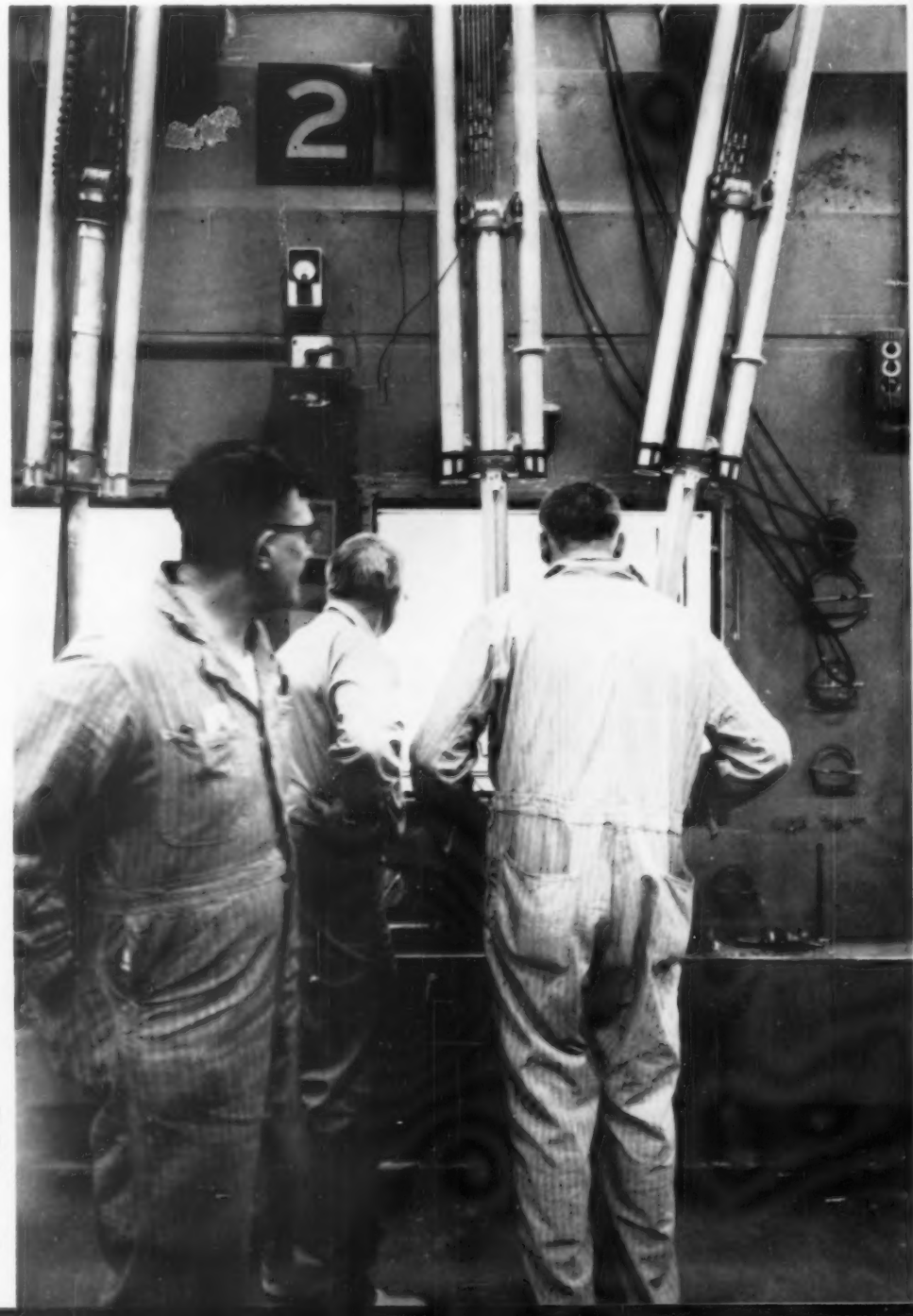
by **Max M. Tall,** *manager of reliability and value engineering, Radio Corp. of America*



***RADIATION TESTS** are used to prove reliability of components for space.*

RELIABILITY: AN ENGINEERING PROBLEM

PRODUCT RELIABILITY is demanding increasing attention from engineers. Major segments of industry, particularly manufacturers of military equipment and on-line industrial equipment, have been concerned with this problem for some time. Now product reliability is becoming a more important consideration in other parts of industry, even extending to manufacturers of consumer products.

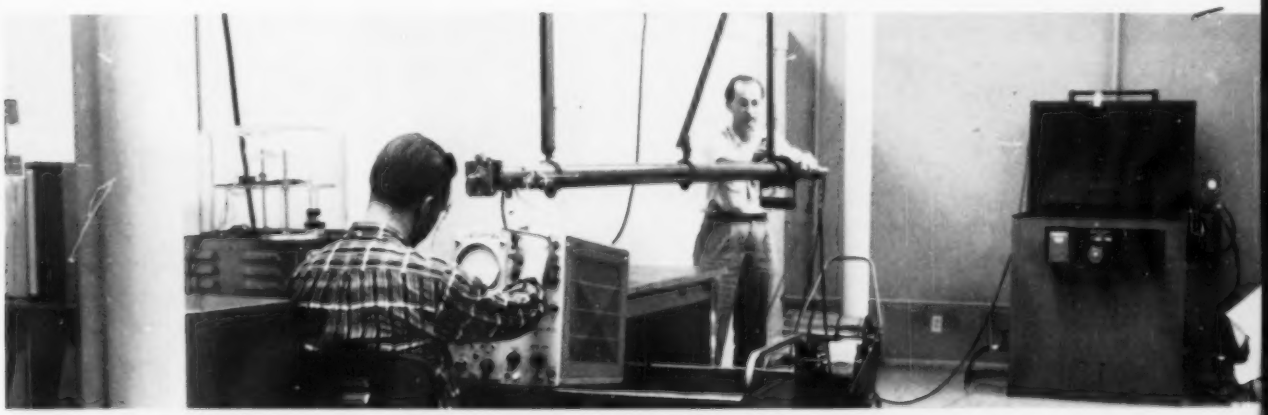
For example, housewives who are urged to purchase new appliances for their kitchens are finding appliances they already own are both difficult and costly to keep in operating condition. The ratio of qualified maintenance men to the amount of equipment in use is decreasing sharply. Resulting poor maintenance and cost of that maintenance may prove a deterrent in the future growth of the home-appliance industry. Home-appliance manufacturers are recognizing this problem and several already have taken the first steps to increase reliability of their products through design simplification and improved quality control.

More dramatic is the loss of a multi-million dollar missile because of the failure of a part having insignificant cost. Changing military missions during the last decade have resulted in equipment with increasing complexity, operating in unusual environments. The use of more components and systems has aggravated the reliability problem, making it necessary to take corrective steps.

A necessity for automation

The interruption of an industrial production line as a result of a control device failing also can be costly. Growth of automation in industry will be directly related to the demonstrated reliability of the automatic devices. A continuing demand for automating more and more complex functions makes the achievement of reliability more difficult. Yet, these additional functions must be accepted, and a product developed to perform them reliably, if the growth of automation is not to be halted.

Reliability relates to trust. A reliable device is one which is worthy of confidence. In technical terms, the degree of confidence in a device is expressed in terms of probability. Reliability may be defined as a probability that a device will perform its intended function within a given environment for a given period of time. There are many more



SHOCK-TUBE TESTS *are performed at Consolidated Electrodynamics Corp. to evaluate a tiny pressure transducer. The loss of a multi-million dollar missile might result from the failure of a seemingly insignificant component, and increased complexity means more parts.*

Reliable equipment needn't last forever, and long-lived equipment may

specialized definitions of reliability, but all have several inherent factors—probability, function, environment, and time.

The last characteristic, time, is the basic difference between reliability and quality control. Quality control is concerned with product characteristics at a given point in time. Reliability, on the other hand, is concerned with the maintenance of these product characteristics with time.

Reliable for an hour

Reliable equipment need not last forever, and equipment with the longest life is not necessarily the most reliable. Reliability is related to the equipment function and is dependent upon the intended application.

For example, a missile to have an operating time of one hour is 100% reliable if no failures occur within that hour, even though it may fall apart if used for a longer time. A control device in a steel mill which fails once a week, on Sundays, may be considered 100% reliable if no failures occur during the work week. In contrast, equipment required to operate 24 hours a day, seven days a week, is not 100% reliable if it fails on the average of once a year. In effect, a device is reliable if it behaves in the expected and desired manner.

Reliability is basically an engineering problem. Characteristics of a device which relates to the performance of its intended function are inherent in the design. Quality control is a manufacturing problem. Its function is to minimize degradation of inherent reliability during the manufacturing process. A cliché, repeated here for those who haven't heard it, is "Reliability must be designed and built into the system; it cannot be tested into the system."

'Good practice' is changing

If reliability is an engineering problem, how does it differ from "good engineering practice?" The answer is that it does not. Then why has reliability become a discipline in its own right, and why are many companies creating reliability groups with people specializing in this discipline?

One answer is that the concept of what constitutes "good engineering practice" has been and still is undergoing many changes. The experienced designer is finding that equipment considered acceptable many years ago is not acceptable today. He is faced with new requirements in both performance and environment. The multitude of problems which must be considered and their solutions are becoming too great for the competence of a single individual.

Expanding technology has created an increasing requirement for engineering personnel to specialize. Yet, even as a specialist, the engineer is experiencing difficulty in remaining abreast of current developments. Additional specialized groups have grown during the years to provide the design engineer with knowledge necessary for him to perform his task. Most major companies have central engineering groups or standards groups with highly specialized personnel to assist the design engineer.

Functions of the Reliability Engineer . . .

- **Determines operational and environmental factors that may affect reliability of the end-product.** (For example, consider the Widget Model HT, a guidance system for controlling a missile to be sent to the far side of the moon. The reliability engineer determines characteristics of the missile that might stress the guidance system and environmental conditions during takeoff, transit, and landing, including radiation levels, temperatures, and mechanical effects.)
- **Assists in translating these factors into design requirements consistent with overall objectives for the product.** (To use the same example, the engineer cooperates with the designer in studying different guidance techniques with respect to performing the task under environmental stresses.)
- **Develops and makes available to design engineers tools necessary for compliance with the product-reliability objectives.** (The reliability engineer shows the design engineers how to estimate life of components and of the overall Widget system for the parts being considered.)
- **Monitors the design to see that these tools are used properly.** (He checks the reliability of Widget components selected.)
- **Assists in the discovery and solution of inherent design problems as early as possible.** (He finds that ambient temperatures are excessive for the tunnel-diode control amplifier and helps determine how much cooling is required.)
- **Monitors performance of the product in its operational environment to assess the degree of success in meeting objectives.** (He checks results of Widget tests to see if required reliability levels are met.)
- **Determines and helps solve problems that prevent the product from meeting its objectives.** (Electrical connectors in the Widget shake loose during vibration, so the reliability engineer finds a new vendor.)
- **Accumulates, and documents for future use, experience gained from the operational evaluation of various design practices and techniques.** (He obtains and studies all Widget test data, so that over a period of time he can determine where the weak spots are—what components have the highest failure rate or changes in characteristics.)

not be the most reliable!

Coordinating specialists

In contrast, increasing specialization has created the need for more generalized groups to direct and coordinate efforts of specialized activities toward a common objective. These groups may have several names, such as product engineering, systems engineering, and integration engineering. A large engineering organization developing a complex product finds that the engineering function might be categorized often as "reliability engineering."

In smaller organizations dealing with simpler products, the categorization may not be as formal. However, if the engineering objectives are to be met, necessary engineering functions cannot be ignored because of their informal nature.

Reliability has been described as "womb-to-tomb" activity. Reliability contributions can be made during initial conception, design, development, production, or field use. To perform these functions, both specialized and generalized engineers are required.

The specialist is intimately involved in the design and development of the product, assisting the design engineer in the selection and application of adequate parts, materials, and processes. The more generalized engineer takes the broader, or systems, approach by evaluating operational requirements in terms of required reliability and environmental conditions; he assists in relating overall reliability to other factors, such as cost, schedule, and performance. The balancing of all these product objectives is vital.

Existence of a reliability group does not lead automatically to a more reliable product. The function of the reliability group must be integrated into the engineering process. First the designer creates a device that works and meets specifications. Normally, cost and schedule considerations prevent him from doing much more. In designing the device, achievement of reliability is a matter of chance. The cost of reengineering a device, when the lack of reliability is discovered, can be many times the cost of the original design.

Value of design review

For example, several years ago at RCA, a comparison was made between two programs. These pro-

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grams were concerned with similar equipment, their only difference being that one had a design review, a major factor in a reliability program, and the other did not. *The program which had the design review had a re-design effort which was one-sixth of the re-design effort for the other program. Yet, the cost of the design review was less than 1% of the original design effort.*

The inclusion of the design review not only reduced cost of the final design, but also reduced time required to achieve that design. Results of this comparison add weight to the argument that the earlier a design problem is discovered, the more economical and less time-consuming its correction.

Purpose of the reliability function is to assure that the company delivers a product that adequately meets customers' requirements. This purpose must be fulfilled in a manner consistent with company policy and procedures as well as with time and cost limitations.

Reliability engineering as a management tool is an audit function. It audits the effectiveness of the engineering function, just as quality control provides an audit of the manufacturing function's ability to deliver equipment of adequate quality. Reliability engineering as an engineering tool, however, should provide additional services to the designer which aid him in meeting his objectives. (See color panel on this page.)

These objectives may be summarized further into three phases of every effective reliability program — *assurance*, *evaluation*, and *improvement*.

The objective of the assurance, or testing, phase is to prevent reliability deficiencies from occurring in the end-product. The evaluation phase is concerned with monitoring the results of the testing phase. Improvement is directed toward removing those deficiencies discovered through evaluation.

Pressed delivery schedules

When large production runs are involved, these three aspects of a reliability plan may be applied sequentially, since sufficient time may exist to correct equipment deficiencies noted in the early production items. However, when a few complex systems are being constructed, a more concentrated approach must be applied, especially when delivery schedules are short.

RCA's Missile & Surface Radar Division, for instance, continually faces this problem. As a result, a sensitive and fast-acting reliability program has been developed to permit concurrent application of the three phases of a reliability program. Continual evaluation of reliability accomplishment in the equipment reveals reliability deficiencies early in the cycle to permit economical correction, and serves to measure effectiveness of the applied program. Key to this concentrated approach is the systems concept.

The philosophy behind this key is that the reliability program, consisting of many detailed facets, exists only to assure that the system, as implemented, can accomplish its intended mission.

Normal measures of reliability, such as failure rate, mean-time-between- failures, and probability of failure, are not adequate in a system which contains redundant elements, or a system subject to degradation or partial failures. In addition to measures of failure frequency, a measure of failure severity must be used.

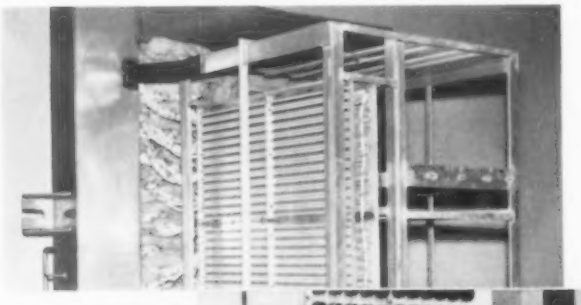
Failure severity reflects the effect of any given failure upon the system's primary role and the downtime resulting from this failure.

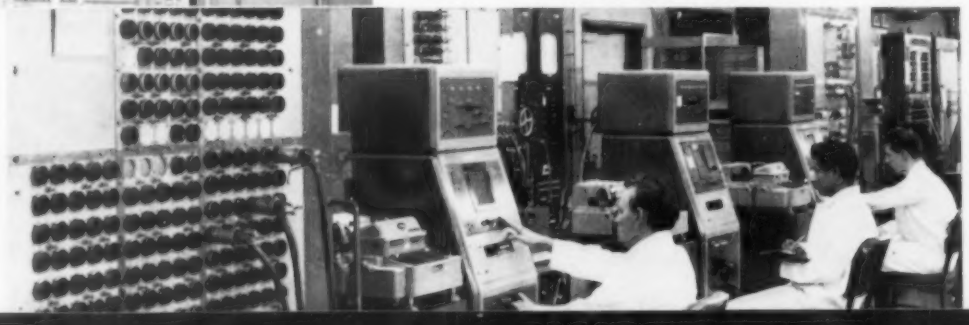
Thus, a reliability measure is desirable which includes both the factors of failure frequency and severity in terms of the system's primary role. This measure may be the ratio of the expected, or actual, performance of the system to the theoretical performance which would occur with 100% reliability. A single measure of system effectiveness thus is created, against which all other factors are measured.

For example, in the *Talos* land-based weapon system, fire-power was selected as the measure, and all portions of the system were evaluated relative to their effect on fire-power. It then was possible to represent system reliability as a percentage of theoretical maximum fire-power under any given set of conditions.

For the Ballistic Missile Early Warning System — a long range ultra-high-speed radar warning network—the primary mission is the timely detection and identification of enemy ICBMs. The probability of detecting and identifying such targets can be used as the measure of system reliability. A single number representing this probability is an easily understood measure of the system's worth.

The effect on reliability of every portion of the system, regardless of how large or how small a portion, can be reflected in the number which becomes a useful tool for optimizing system configuration, as well as for evaluating the relative importance of any portion of the system in the overall reliability picture.





LARGE-SCALE TESTING *requires automated equipment and system for recording data. Shown left and below is a system for testing up to 5,000 parts, such as resistors, diodes, capacitors, or transistors, located at Inland Testing Laboratories Div. of Cook Electric Co. The test parts are mounted into the door assemblies (rear view at left), which can be moved from chamber to chamber for thermal cycling. Data are recorded on punched tape and digital printout. At right is an accelerometer that can apply an 100-g force to 600 pounds.*

Reliability model

During system studies, a reliability model is created to represent weighted contributions of various components to the system's reliability. With establishment of overall reliability objectives, this model is employed to allocate reliability requirements to elements of the system.

Predicted performance curves are established to show relationships among reliabilities of the various elements, their effects on system reliability, and costs in achieving these reliabilities.

An ordered list is established for each system element based on the ratio of increased system reliability to the cost of improving the element. This permits directing reliability efforts to those areas where the greatest system improvement can result from a given investment. The system concept approach underlies the reliability effort and provides the basis for decision throughout the process.

The initial step in the design phase is establishing necessary specifications. A general specification is created, if none exists, to cover selection and application of parts, materials, and processes. In addition to reliability benefits from using standard parts and proven practices, benefits result in reduced time and cost of design, manufacturing, and logistic support. The reliability engineer monitors adherence to the specification and assists the designer when he must depart from specifications.

Using accumulated experience

One of the more important aspects of a reliability program during the design process is design review.

Design reviews should be conducted by engineers having extensive experience with the type of equipment concerned. Consultants may be brought in from other divisions of a corporation, as well as from outside when required.

The design review provides an excellent mechanism for bringing a company's accumulation of experience to bear upon every aspect of the equipment design. At RCA, three electrical and three mechanical reviews are held on each unit of equipment, although additional reviews may be conducted when necessary. These reviews are called preliminary, major, and final.

A preliminary design review is held after the design engineer has reviewed the detailed specification and evolved an approach to meet it. The specification is re-examined as to the practicality of compliance and for consistency with overall system requirements. The designer's interpretation of the specification as well as his approach to meet the specifications are discussed. Preliminary design approval permits the designer to proceed with the prototype phase.

Hazard of non-standard parts

During development of a prototype, the designer works closely with the reliability engineer in selecting and applying parts. Requests for use of non-standard parts are reviewed critically. Not only are the needs for the parts examined, but effort is directed toward designing the "needs" out of the equipment even when they have been justified.

When non-standard parts must be used, a comprehensive evaluation is undertaken to determine that these parts can meet the reliability requirements of the system. Sample parts are scrutinized carefully to determine if proper material, design, and workmanship have been employed. Parts also are subjected to a series of environmental tests. Should they fail to pass, the vendor is requested to re-design and submit new samples. The process continues until suitable vendors and parts are found.

Test results on non-standard parts are maintained in a central file for future reference. Hence, it is found frequently that a desired non-standard part already has been tested and approved for use in RCA equipment. Test results on these parts are examined to be sure of their applicability and that all the pertinent characteristics have been tested. In addition, the field-failure history of non-standard parts employed in other RCA equipment is studied to determine the desirability of including them in a new system. Field-failure history exerts a strong influence on the original selection of standard parts for the system.

Prescribing more reliability

After prototype testing, the designer performs a reliability analysis to determine whether desired reliability requirements have been met. If he has not met the requirements and is unable to do so through redesign, reliability specialists are brought in to assist.

In case of difficulty, predicted performance curves developed during the system phase are used to determine where additional reliability must be incorporated. Advanced development and parts improvement programs may be undertaken as a result of the investigation.

After completing the prototype phase, the design is subjected to a major design review. Every aspect of the design is scrutinized. Typical of these aspects are parts selection and application, materials and finishes, performance, reliability requirements, cost considerations, ease of production, ease of maintenance, and so on. Following this review, the equipment then may be released for production.

After the equipment has been produced, combined with other equipment, and tested for a reasonable time, the system is subjected to a final design review. Operating and maintenance experience are examined carefully as a further check on design optimization.

It may appear from the description of the program that reliability enters the design process at several predetermined points. This is not true. Actually, the reliability engineer works continually with design personnel to assure minimum difficulty in the final equipment.

The reliability program above is discussed to explain the contributions that reliability enginering can make in a development program. The degree of effort required depends upon a company's objectives and on cost and schedule considerations. A determination must be made whether it is more timely and economical to practice prevention—that is, to assure the achievement of reliability objectives— or to correct deficiencies when discovered later in the process. Regardless of the balance employed between reliability assurance and reliability correction, an organized approach must be integrated into the engineering process. ■

John Connor joined Hughes in 1957 to establish an engineering reliability section, and he later was appointed to his present position. Previously he was with RCA, as manager of the measurements engineering laboratory; Leeds & Northrup, as senior engineer for the development of scientific instruments; and the Naval Research Laboratory, as a member of the engineering staff conducting research on acoustical measurement standards and electronic parts and materials. In 1959 Connor received an annual Institute of Radio Engineers award for development of methods for reliability prediction. He holds a BSEE degree from Illinois Institute of Technology, and an MSEE from the University of Pennsylvania.

by **John A. Connor,** *manager of reliability and engineering services, Hughes Aircraft Co.*

BASIC RESEARCH *on materials contributes eventually to improved reliability and makes it possible to meet new requirements. A useful experimental research facility is the Van de Graaff accelerator at Argonne National Laboratory. The view here is on the inside looking at the instruments.*

RELIABILITY: A MANAGEMENT PROBLEM

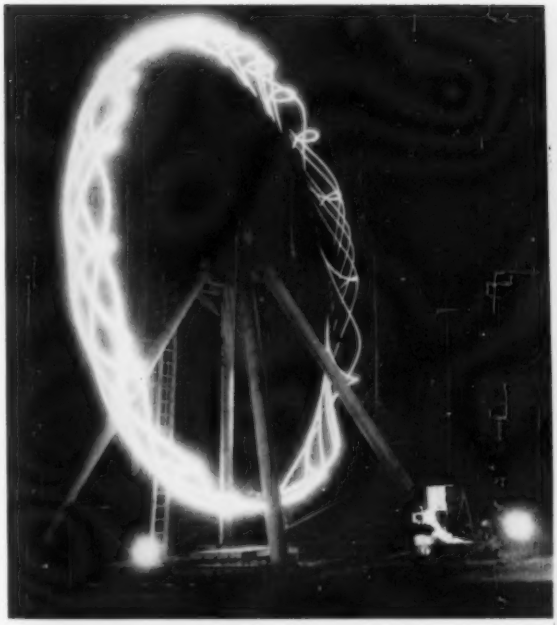
ADMITTING DEFICIENCIES of any kind is never a happy experience.

The inherent deficiency of a complex, electrical, mechanical, pneumatic, or hydraulic system is the chance that the system may fail to perform its function. The chance of difficulty increases when each new component is added to increase the versatility of a system. Because chances of error or failure in performance are cumulative, the overall system often looks like a poor risk when it becomes complex.

How can management foresee the occurrence of poor reliability? Prevalent circumstances would indicate a need for extraordinary management concern.

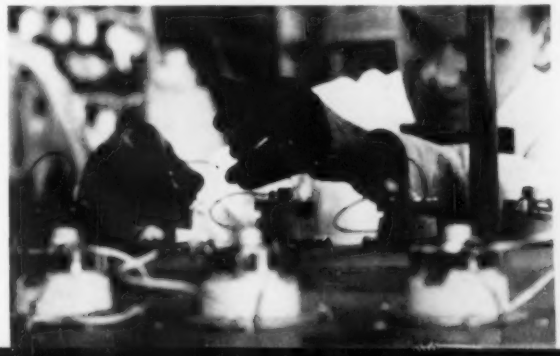
Operational unreliability has proven so serious in some instances as to cause destruction of valuable property and invaluable lives, and even shape the strategies of international politics. Closer to the engineering manager are threats to his basic objectives—delivery schedules, customer satisfaction, and profit. A new product, delivered on schedule and at a competitive price, may be incapable of performing for an adequate period.

Basic incentives of the national economy are built upon business risks—a fair game when such risks are clear and accountable. Reliability risk factors, fortunately, also are susceptible to analysis and control. Management need not become expert in the language and subtleties of reliability engineering to take suitable action when a reliability crisis arises.



LIKE A FERRIS WHEEL *in an amusement park, this boom for testing missile components makes a striking pattern at night, as it revolves on a radar range at Aeronutronic Div. of Ford Motor Co. Seemingly endless techniques for evaluation of components and systems have been devised to assure operational reliability.*

HIGH-TEMPERATURE *tests are to be performed on semiconductor components mounted in this special oven. As requirements grow for equipment to operate at increasingly higher temperatures, designers must try out new materials.*



Era of the critic

Reliability engineering and maintainability engineering are akin to safety engineering and quality control. Now a new relative, called value engineering, has appeared upon the scene.

Each function has its preventive and corrective aspects. Probably all suffer from a tendency to act the role of the missionary: viewing with alarm and providing voluminous advice. How are these promotional programs related to each other? Although often dealing with the same object, they seem to differ mainly because of their orientation to a par-

ticular audience.

Safety engineering concerns the operator.

Maintainability engineering concerns the maintenance man.

Quality control concerns the procurement team.

Reliability engineering concerns the design engineer.

Value engineering concerns the business man.

Reliability is faith

Reliability is faith (expressed numerically if possible) that a device, process, or organization will work. Thus, the engineering ingredients of reliability pertain to the fitting of a thing into its functional environment. The tools of the art are a whole range of design techniques with particular emphasis upon statistics, testing, and safety-factor analysis.

Whether this work is done by design or reliability engineers does not alter the basic mission of any reliability (or design integration) endeavor.

Quality control, on the other hand, enhances the quality of a product by assuring conformance of items to prescribed procurement or engineering specifications.

The goal of reliability engineering is to assure that apparatus will function or stay functioning, rather than to achieve new functional characteristics. Nevertheless, reliability know-how is best put to work in the earliest possible phase of design. It is understandably difficult to divert normal design efforts to reliability tasks because the payoff from these efforts comes after demonstration of performance feasibility under nominal environments. Consequently, a situation exists which commonly results in a too-little-too-late reliability effort.

Freedom to create a new design based upon sound premises, followed by an exacting reliability analysis, seems to provide a healthy compromise with the timeliness problem. The more ambitious the functional design, the more necessary is the review of value, reliability, quality, and safety.

Feedback in reliability

Reliability criticism can be likened to a servo system, where a second go-around is best accomplished by an accurate and frank appraisal of all initial errors and omissions. To carry out his role, the reliability manager must demand and get a complete picture of every incomplete or mistaken design judgment.

Discretion requires a knowledge of the reactions of creative people at all levels. Skepticism, in the guise of a reliability effort, should start early. Questioning the realism of specifications cannot be delayed in any program. Attention to the hardware alone is not sufficient, since the implementation of reliability policies must be smoothly organized and sold as a continuing effort to upgrade standards of excellence.

Which risk to take?

One of the often-repeated demands of management is for an improved awareness of costs, schedules, or profits. Fundamentally, the need is for an assessment of risk from the numerous business summaries available. The existence of risk is not questioned; it is only the degree of risk which must be determined, whether for an assemblage of hardware, or the performance of a team of engineers.

The reliability engineer is concerned with evaluating and minimizing these risks, and thereby optimizing the probability of success of an end item or service. The risks associated with any claimed technological breakthrough should arouse a skeptical attitude. How can this be accomplished without being reactionary at the expense of progress and competitive success? Here is probably the most sensitive aspect of management's functions related to reliability.

It seems paradoxical that product-design management should have difficulty selling reliability programs which can reduce production runs, field service, and replacement equipment. Objectives of reliability efforts often are considered by the customer as too good to ignore, but too far off to provide a basis for serious planning.

Management can help assure a meaningful reliability effort by recognizing the inherent purposes and limitations of reliability programs. Design management cannot afford to resurrect an otherwise dormant reliability program only in an emergency. Customer project managers who use fragmentary or inadequate reliability evidence as a signal to generate condemnations are scuttling the cause of an embryonic science. All too often in recent years, reliability has been the justification for a show for the customer, or an inquisition for the vendor, all out of proportion to the capability of reliability methods for counteracting deficiencies.

Speak softly, act strongly

Management may assign varying importance to reliability factors, but cannot justify their omission from product design and utilization. Nevertheless, it is far better to omit reliability efforts from a program than merely to talk about it as a means of gaining an unwarranted level of confidence. In reliability matters, honesty is the best policy.

The admonition to go softly on reliability salesmanship does not change the need to form strong, management-supported policies toward reliability objectives.

At a high management level, policy is formed, and at lower or organizational levels, reliability is under the direction of specialists. Managers of electronic projects, for example, have been too slow to recognize the reliability aspects of long-existing programs. Efforts toward standardization, development of new parts and materials, and promotion of measurements engineering and environmental test engineering must be given a renewed emphasis in any meaningful reliability program.

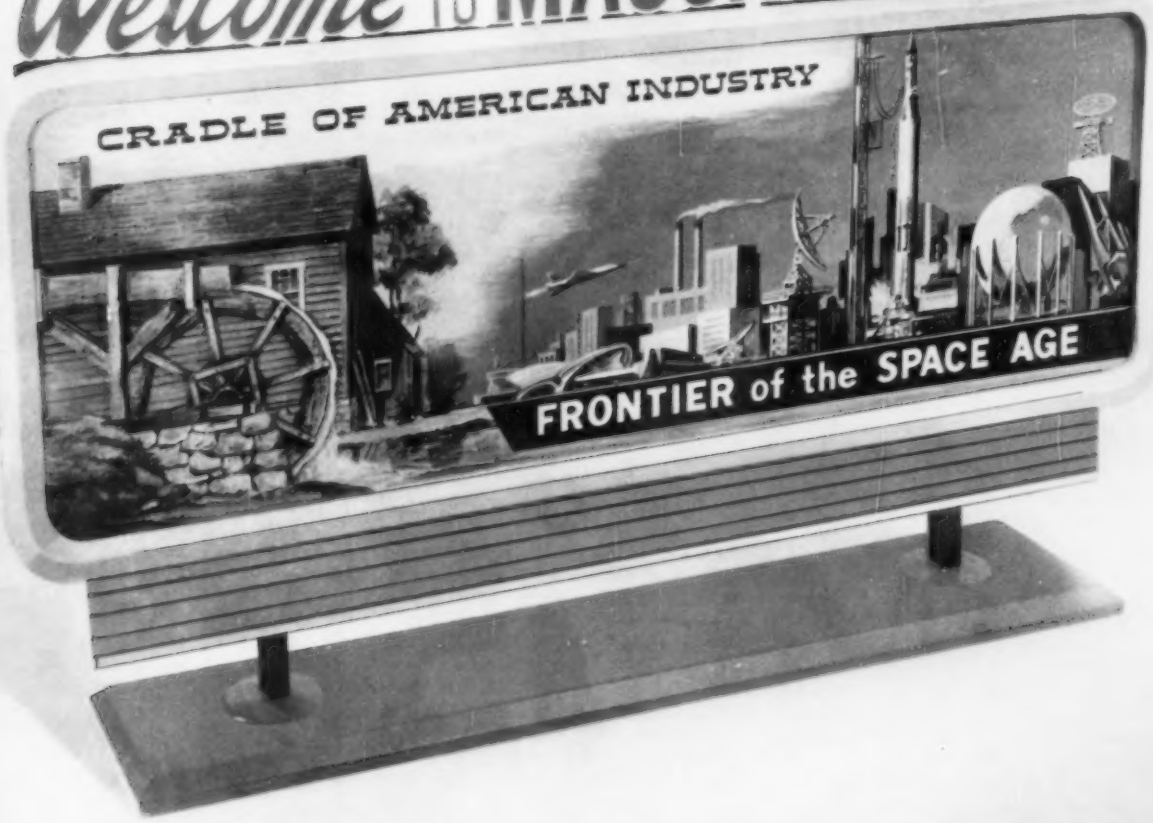
When these efforts are integrated with design-review and statistical prediction, they form an effective program. Integration by management faces an interesting paradox in bidding and scheduling, since customers often request a "reliability program" as a separate entity. Future project managers may be less likely to place artificial boundaries around the reliability issue. Presently, salvation is to be found in reliability-program specifications which describe individual tasks in a well-defined overall program.

How to measure it

The newest tools of analysis use numbers to measure reliability. Numbers may be assigned to:

- The inherent reliability (designed-in reliability) of a device or system.
- The availability of an equipment or system for a mission.
- The successful accomplishment of a mission.

Welcome to MASSACHUSETTS



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Mathematical probabilities expressing these important values can be derived and used to monitor a product or service. The second and third factors are very dependent upon a customer's use of any product.

Ideally, a mathematical model of reliability should provide a rigorous means of assigning design requirements for all contributing design teams. Unfortunately, the sciences of reliability prediction, reliability control, and reliability testing have not progressed that far. Reliability prediction methods currently available for electronic equipment analyses have principal merit as screening criteria—for judging the manner in which circuit elements are used. Accuracy in a reliability prediction is possible only for a complex system where errors tend to compensate.

It is over-optimistic to employ existing methods for computing reliability increments (corresponding to individual part changes) and argue that a demonstration of reliability improvement is provided. The big issue today is how to proceed in the light of existing limitations and yet expend funds wisely, despite inability to demonstrate increments of improvement by calculation or tests.

A practical reliability formula for management is: exploit all means of assuring the best level of reliability and then attack proven deficiencies through processes of up-grading.

Creativity and bizarre design

Engineering products are based upon concepts and adaptations of creative people. The capabilities of such people affect the quality of a product and its inherent defects. Management should assess the motivation of product designers and ferret out tendencies for bizarre or needlessly unusual designs. Management can assist materially in developing optimum products by appreciating and encouraging creative growth, but at the same time testing unproven speculations.

In the cause of reliability, academic training for product engineering has been said to be inadequate. Learning proficiency certainly does not assure competence in product engineering creativity. Management must improve its ability to measure this inherent capacity of engineers and teams as a means for promoting the reliability of a new product.

Industrial management and academic institutions have a joint mission to prepare engineers (both intellectually and emotionally) for product responsibility.

Formal reliability practices are beginning to require design-review sessions to inject criticism into design functions previously considered private domains. Forthright criticism is not an easy task. Reliability reviews conducted crudely, with only a superficial management knowledge of product objectives, can go far toward damaging design creativity. The degree to which management can implement design reviews will measure the effectiveness of management for improving reliability.

Forgotten ingredient: standardization

The forgotten ingredient of reliability is standardization. Because standard items are never new or glamorous, designers have a strong inclination to use something newly designed. This can be hazardous.

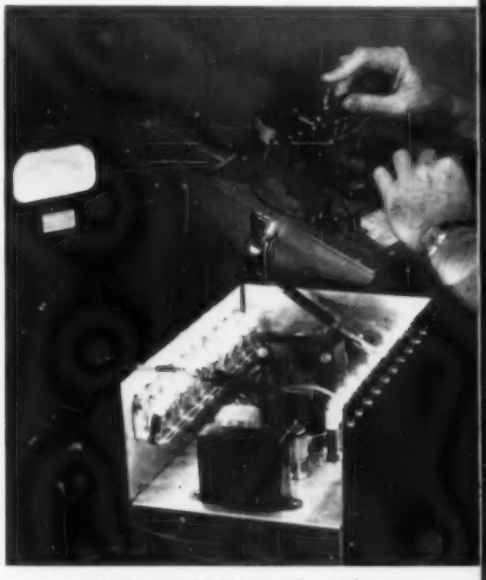
But a design organization geared for reliability (and efficiency) will have diverse investigations conducted by specialists in their fields, wherever this talent can be found. There is always plenty of room for each designer to enhance reliability through the ingenious adaptation of elements and the control of environments.

For example, in designing electronic equipment, a designer might study variations in the temperature of various parts of the system, then locate components most susceptible to degradation from high temperatures in locations where temperature is lowest. Other environmental factors which might affect the selection or location of components include radiation, pressure, humidity, shock, vibration, etc.

Unfortunately, novelty and patentability remain the most tangible evidence of merit to the design engineer. Management can spare a reasonable acclaim for the designer with an eye for the reliable or conservative approach. Probably the worst thing that can happen for the cause of reliability is for a new device to work the first time it is energized. Optimism under these conditions makes it almost impossible to check tolerances and safety margins which have meaning only in terms of a statistical spread of like items.

Thus, the crucial time for reliability in the life of a product is at its birth, when a fine balance of faith and skepticism is necessary. Creativity, however, must not be thought to end with a demonstration of feasibility. The product depends upon a succession of vital decisions all along the path from concept to field utilization.

STEEL CREEP, *or very slow extension with time, is an important design parameter, particularly at high temperatures. This test equipment for measuring creep is at U. S. Steel's research laboratory near Pittsburgh.*



NONDESTRUCTIVE, *accelerated life tests are performed at Stanford Research Institute to predict lamp life. Predicted life is based upon change in parameters after short-term operation.*

Evidence of unreliability goes along with copies of hardware produced. When reliability is inadequate, excuses can be found in many quarters—most having some validity. In the past, blame was commonly passed along to the parts supplier; there were no discernible contributors beyond this point.

Recent years have seen a return to sanity, and the users of parts are at fault to the extent that application techniques and environments have an effect. Penalties of unreliability provide the feedback needed to achieve reliability optimization. Good data on failures from the field are hard to get. The mission of field-service personnel normally is to get equipment to work in a minimum time. This practice obscures the measurement of inherent reliability, but is justified as a means of maximizing the potential success of any given system.

Thus, we cannot expect too much information from field evidences of inherent unreliability. Management should recognize the difficulty of getting feedback and should integrate reliability and maintenance activities.

A reliability goal must be supported with the means of implementation and proof, or we invite being pacified without concrete attainments. Factory tests merely can simulate simple usage conditions. Statistical sampling techniques now available can force a totally untenable "producer's-risk" situation when an economical or short test program is used.

Consider the stress resulting when a single random occurrence prevents shipment of a complete lot of complex devices representing many months of painstaking effort. Presently available statistical tests for reliability have proven inadequate; new techniques must be developed and proven.

The search for failure

Standing behind manufacturing, with its emphasis upon craftsmanship and quality, an engineering organization cannot relax its interest in product reliability. But in its search for evidences of unreliability from field failure data, factory test data, or qualification tests, engineering may well verify that an inadequate level of reliability exists and yet see no clear course of action toward improvement.

Across-the-board upgrading of reliability probably will never be attractive as an economical means of product improvement. Introduction of priority corrective measures, based on adequate data, is the only proper course of action. Tendencies to introduce psychological warfare into such circumstances, either by management or the customer, tends to delay or divert effective measures and substitutes a panic condition.

These crises demand the most competent managerial judgment to produce the optimum compromise among costs, schedules, and reliability. There is no substitute for a mutual appreciation between the customer and the designer regarding the basic net worth of reliability achievements.

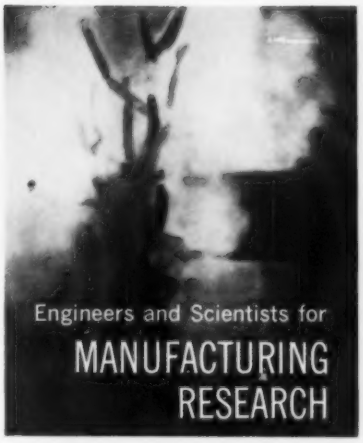
Readiness to change

Many reliability practices can be instituted only through management awareness and action. Probably the key to achievement of reliability lies in management's ability to schedule all phases of a product program with accurate timing and a readiness to change schedules where mandatory. All too often, schedule changes early in a program are compensated for by the simple expedient of reducing subsequent efforts.

Another contribution that management can make is perseverance. Initial design strategies should not be abandoned at the first evidence of trouble. Leadership and authority rest with management because it has a vested interest in a sustained target for the design process.

In a product design effort, education is the primary step toward reliability; education without management support is destined to fail. Reliability efforts must enhance the use of quality-control techniques which, in turn, should start at the earliest practicable experimental-hardware phase. Management can contribute materially to the awareness that designers have of the end-product of their creations. When the first significant operating experience is gained during production or field-test phases, reliability always suffers. But turned loose on the tasks of reliability accomplishment, creative designers can be expected to produce results.

Management must be wary of and yet responsive to subjective reliability evidence. However, reliability measures may become meaningless when "failures" become a political issue rather than an engineering statistic. It is wise to maintain the same unemotional objectivity toward the 2% that fail as toward the 98% that succeed. Reliability activity is an asset only to the stable organization that builds upon prior experience. This effort eventually will yield an overall history of accomplishment. ■



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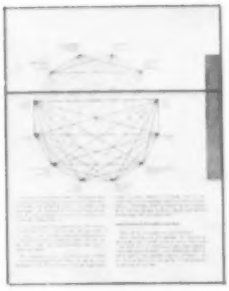

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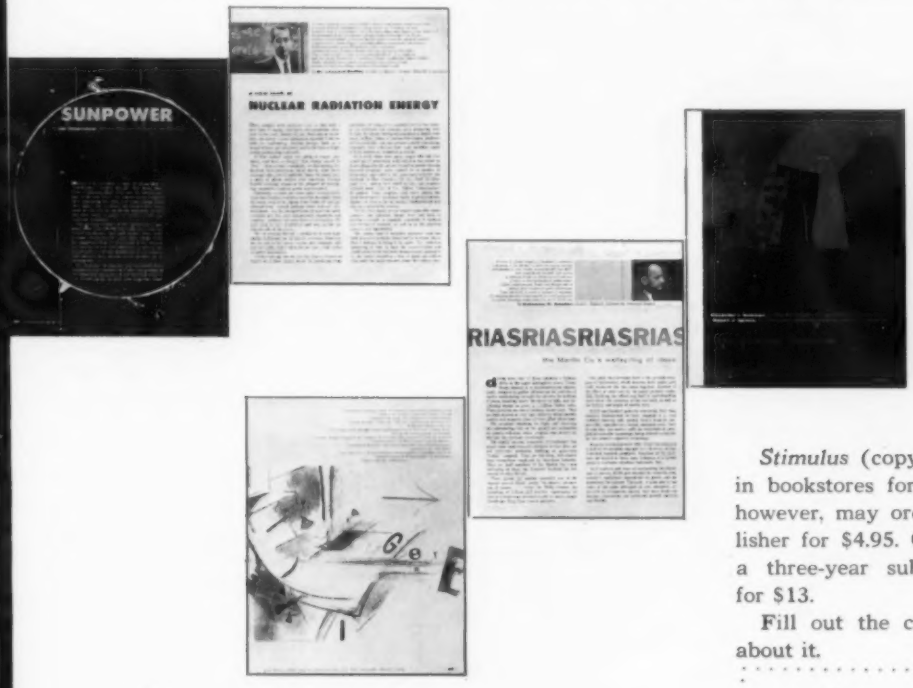

A few of the pages from Stimulus

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'Suddenly, the instrument panel began to melt, very slowly at first, progressively faster within a few seconds or minutes, until finally, my instrument panel actually was dripping on the floor. This induced a surprising degree of panic because I was trying to increase my proficiency while having to cope with indicators I could not read because they were melting, dripping on the floor.'

by **H. L. Williams,** *supervisor, human factors engineering, Melpar Inc.*

For more than 10 years, H. L. Williams has worked in human-factors engineering and related fields. His activities have included display design and evaluation, layout of working areas, studies of man-machine systems, design and evaluation of training equipment, and prediction of human-error probabilities in weapon systems. He received his AB degree at Ohio Wesleyan University, and has done graduate work at several universities.

human-factors ENGINEERING

STUDENT-GUINEA PIG *tests (left) are providing data on properties of the human at the University of California at Los Angeles. In this hot box, the temperature is more than 200° F, and the subject is sweating profusely, as might be expected. Some subjects have withstood 250° F for 14 minutes. UCLA has been instructing in human factors since 1946. An aerial reconnaissance game (right) is part of a research project designed to study information processing and decision making in complex systems at Ohio State University's Laboratory of Aviation Psychology. Students gather around a plotting board which is used to referee a game between two opposing teams.*

THE EXPERIENCE, at left, reported by a test subject after exposure to a 30-hour space experiment conducted by the Air Force School of Aviation Medicine, was a hallucination. The subject had been concentrating on an instrument panel in a simulated space capsule.

Other subjects experienced similar hallucinations. One thought the walls of the chamber were closing in on him. Another saw gremlins.

Results of these studies emphasize a problem facing designers of space equipment — making the equipment and its operating environment compatible with the human operator. How well designers succeed will depend to a large extent upon a new engineering discipline which has come into existence during the last 20 years. It is known by several names: applied experimental psychology, engineering psychology, human engineering, and human-factors engineering.

How it got started

Human-factors engineering can be traced back to time and motion studies, experimental pyschology, and personnel selection. Time study, originated in 1881 by Frederick W. Taylor, involves measuring the time required to do a job. Taylor used it in determining the best working rate on which to base pay scales. Machine-shop workers were highly suspicious of Taylor and his methods; he became practically an outcast.

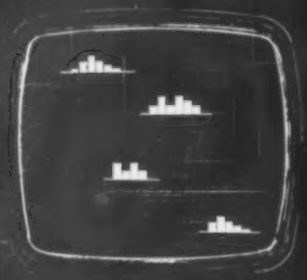
Credit for motion study goes to Frank B. and Lillian M. Gilbreth. Motion study is concerned principally with the manipulations or movements made by an operator in performing his job, including an analysis of these movements to determine the best way of doing the job.

Eventually, time study and motion study were brought together and became a tool widely used by industrial engineers.

Experimental psychology dates from about 1881. Traditionally, experimental psychologists have studied normal human beings. Experimental research, conducted primarily in the university laboratory, has been devoted mostly to human vision, learning, tactual sensitivity, and motor behavior.

Personnel selection was started by psychologists who became interested in the wide differences among people. People differ in their ability to see, hear, smell, move, and to solve problems. During World War I, this interest really bloomed. Personnel psychologists were able to test vast numbers of people to find exactly how they differed in various abilities. Intelligence tests were born of this research.

Observed differences in abilities of people led to a general attempt during WW II to deal with the



Visibility of a CRT signal to an observer is affected by:

1. Rate of signal presentation.
2. Time the signal remains on the scope during each presentation.
3. Area of the signal.
4. Intensity of the signal.
5. Color of the signal.
6. Rate of decay of the signal.
7. The number and proximity of the signals presented simultaneously.
8. Intensity of the background light.
9. Color of the background light.
10. Level of preadaptation of the observer.
11. The ambient light level.
12. Reflection of ambient light from the glass shield in front of the CRT.
13. Viewing distance.

MANY VARIABLES *determine visibility of a cathode-ray tube pattern, and many combinations are possible. Intensity, background luminance, and other parameters are varied to obtain a signal without flicker. At low frequencies, viewers become drowsy or hypnotized, and may develop headaches or nausea.*

problem of human errors in operating military equipment. Efficiency of a man-machine combination could be improved radically by utilizing results of personnel selection studies, frequently by as much as 15 to 35%.

Reducing human error

Success of this effort greatly stimulated interest in means for reducing the number of human errors. Psychologists began using time-and-motion engineering techniques to identify and describe operator tasks. Tasks were examined in light of known human capabilities established by research in experimental psychology and personnel selection. By altering design features of equipment on the basis of this examination, operator performance could be improved.

Gradually, techniques for analyzing human performance in man-machine systems were formalized. Principles of design for human use were compiled, and thus human-factors engineering was born.

Following WW II, the military continued its emphasis upon human-factors engineering. The armed services established research centers to obtain information needed in the design of increasingly complex weapon systems. Consulting organizations sprang up by the dozen and offered services both to the military and to industry. Human-factors requirements began to appear in procurement specifications.

To cope with these requirements, industry established human-factors groups within their organizations and now employs about half of the professional people in the field. The Human Factors Society of America was formed in 1957. Today human-factors engineering has come of age.

Compatible man-machines

Human-factors engineering is based on the concept of man and machine working together as a system to perform an assigned task. Man is a system component having certain capabilities that can be modified only a limited amount through training. The machine is a variable, particularly in the early design stages. Human-factors engineers seek the design which will maximize compatibility with the human operator.

The human-factors engineer does not work alone, but is one of several specialists whose job is to produce a workable design. In designing a large system of electronic equipment, for example, he works with systems engineers, electrical and mechanical engineers, and others—collectively a design team.

Key man of the team is the systems engineer. His job is to plan, analyze, and develop the overall systems concepts, act as a clearing-house and channeling center for technical knowledge, and develop maintenance concepts, operating procedures, and testing programs. He has a general familiarity with all the areas covered by other specialists on the design team, but is related more closely to function than to design detail. For example, he is familiar with the input, output, and function of a particular component, but leaves internal design considerations to the component specialist.

Who does what?

To the systems engineer, the human-factors engineer is much like any other component specialist. The two work together in determining the human's role in the system. Usually the first assignment of functions is made by the systems engineer. The human factors specialist checks such tentative assignments, and if he doesn't agree with the systems engineer, both propose and counter-propose until satisfied that the best assignment of functions has been made.

The human-factors engineer also works closely with electrical and mechanical engineers. Design features of consoles, controls, and displays are as important to the electrical engineer as to his human-factors associate. The electrical engineer makes tentative selections of switches and indicators on the basis of characteristics and operating tolerances. He determines if it is necessary to locate electronic components close to associated controls and displays to meet the tolerances.

Like the systems engineer, his decisions are influenced by other factors, such as maximum permissible size of equipment, amount of money allotted, state of the art of component design, component reliability, and specification requirements.

The mechanical engineer is responsible for packaging the equipment in the system. He is concerned with size and weight of the equipment, structural strength, cooling of components, and space requirements of components, and to this end may insist that features of the equipment be designed in a particular way.

The successful design team is one that achieves close working relationships. But even then the job is often difficult. When the system borders on the state of the art in design, severe problems may arise. Systems and component engineers may resort to new and untested assignments of functions to the human, and then the human-factors engineer has new problems. The following case history illustrates some of these problems and methods used to solve them. Details of the case history have been changed somewhat because of contract and security considerations. The approach, however, is authentic.

Case history of a computer

To develop a large computer system on an accelerated schedule, a special project group was formed and a human-factors engineer assigned to make sure the equipment could be operated and maintained with ease and a minimum of error.

Inputs to the computer system were to be data describing aircraft movements. The function of the computer system was to sort and

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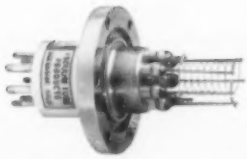

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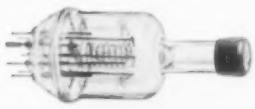

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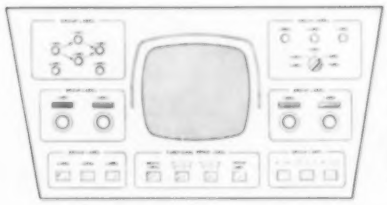
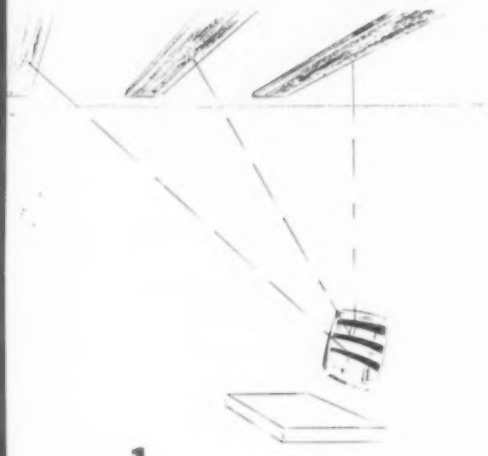
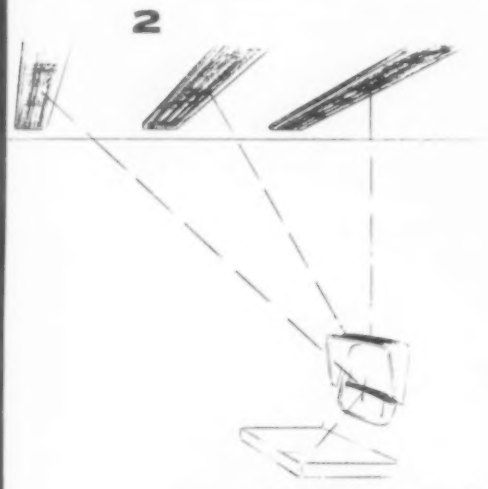


MOST IMPORTANT DISPLAYS, *such as the cathode-ray tube of the case history, are given the most important spot – in the center. Controls and displays are in functional groups, with each group prominently labeled. Controls and displays used least are located farthest from the center.*





LIGHT REFLECTIONS *can be objectionable (see diagram 1) An eyebrow-type hood placed over the cathode-ray tube (diagram 2) eliminates effects of overhead lights. Lights behind the operator are arranged so reflected light is down, rather than back into the operator's eyes.*

classify the data, perform complex mathematical computations, and print out results.

To establish a design plan, the human-factors engineer and the systems engineer worked out an assignment of functions to man and machine. In general, human functions should be those requiring ability to detect and identify complex patterns of light and sound, make judgments, reason inductively, improvise and use flexible procedures, handle improbable events, and store information for long periods of time. Equipment functions should be those requiring high-speed operations, large amounts of power, rapid and accurate computation, repetitious and routine operations, simultaneous operations, and short-term memory.

For example, it was decided that human operators would program the sorting, classification, computational, and print-out operations performed by the computer. The next problem involved data presentation. The systems engineer proposed displaying certain information to an operator by means of a cathode-ray tube (CRT), requiring that the operator use his pattern recognition, reasoning, and decision-making abilities to classify it, and then operate controls to enter data into the computer.

But the human-factors engineer felt it necessary to investigate factors influencing visibility of CRT signals (see illustration on page 38). One factor was the possibility of flicker in the signal. To see the signals on the CRT and operate associated controls, the operator would have to sit within 28 inches of the display. In a television set the picture is presented at the equivalent rate of 60 times per second; yet, at 28 inches, flicker often is apparent.

According to the systems engineer, the number of signals to be presented simultaneously on the CRT made it technically impossible to achieve even a 60-cycle-per-second rate of presentation.

Information concerning the effects of flicker indicated a possible problem. At 9 cps, experimental subjects have reported a sensation akin to falling asleep; they "feel hypnotized," or drowsy. Frequently subjects also reported headaches, nausea, and painful or disturbing sensations in the eyes.

At frequencies from 15 to 17 cps, apparent brightness of the signal is increased considerably. The apparent increase in brightness gives a glittering, frequently unpleasant quality to the signal. This unpleasantness may be accompanied by headaches, dizziness, nausea, and feelings of unreality.

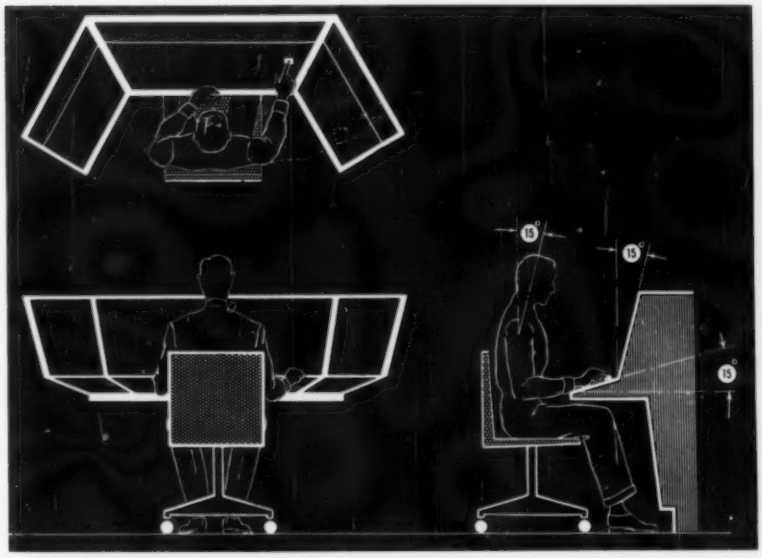
Above 17 cps, visibility of the signal becomes improved progressively until a point is reached at which the signal seems to become a steady light.

But a number of factors other than rate of presentation affect the rate at which a light signal fuses or appears to become a steady signal. Fusion could be obtained at rates of presentation below 40 cps for the right combination of variables. Unfortunately, insufficient information was available to determine what this combination should be for signals on a cathode-ray tube.

Only one solution appeared to be feasible—mock up the CRT display and vary the signal and background parameters until a usable combination could be found.

The remaining assignment of functions to the human operator was straightforward. The operator

WRAP-AROUND CONSOLE *configuration brings all controls within easy reach of the operator. Angles are chosen so the operator looks at the central display perpendicularly, and so his arm rests comfortably when manipulating controls. Color selected for the console is a light, non-reflecting gray. Lettering is black to prevent the labels from getting dirty, as white letters tend to do.*



was required to monitor status and malfunction indicators to make sure his equipment was operating properly. Control functions included processing data displayed on the CRT and entering results into the computer.

The next task of the human-factors engineer was to work with component specialists and model-shop technicians in constructing equipment mock-ups. The cathode-ray tube was located centrally on the operator console, a position reserved for the most important and frequently used displays. Infrequently used controls and displays were located farthest from the center of the console.

The operator console was designed in a wrap-around configuration so all controls would be within reach (see drawing on page 41). The lower edge of the console, used exclusively for operating controls, was designed with a slope of 15 degrees from the horizontal, and the upper part of the console was designed at an angle of 15 degrees from the vertical.

A 15-degree slope from the horizontal makes it possible for the operator to rest the heel of his hand on the console surface when manipulating controls. The average inclination of most people's heads when viewing a console is 15 degrees from the vertical. By designing the upper panel of the console 15 degrees from the vertical, the operator's view intersects the panel perpendicularly at the point of most frequent viewing.

Controls and displays were located in functional groups. Labels of the functional groups were made larger than labels of individual controls and displays for ease in distinguishing between the two types.

Something had to be done about the reflection of light from the face of the CRT. An eyebrow-type hood placed over the CRT eliminated effects of overhead light (see drawings on page 40). Lights behind the operator were arranged so light striking the CRT below the eyebrow was reflected downward rather than back to the operator's eyes.

Push buttons were used extensively for on-off functions. Wherever possible, switches were used which could be pushed for "on" and pushed again for "off." Round knobs operated control functions requiring continuous rotation. Bar knobs with pointers were used for selector switches. Color selected for the console was a light, non-reflecting gray. Lettering was black to prevent the labels from getting dirty as white letters sometimes do.

Upon completion of the mock-up, the design team went to work on operational procedures for the equipment. It still was not known whether the operator would be able to do his job with the necessary ease and accuracy. After further, more-detailed study, several controls and displays were relocated. The critical part of the system was the CRT. If the signals proved to be adequately visible, the operator would be able to carry out all required tasks.

Electronic engineers set up a CRT display a few days later. Frequency of signal presentation was set at 40 cps, the minimum that would be required. Intensity of the signal, luminance of the background, and other parameters were varied until a combination of parameters was obtained that seemed to eliminate the flicker.

As an experiment, 30 engineers and technicians of various ages viewed the signal. Looking straight at the tube, none could see flicker. A few could see flicker using peripheral vision. Visibility of the signal was excellent. Since only direct vision would be required, the signal was deemed adequate.

During the development period, the human-factors engineer also devoted time to maintenance de-

sign. He studied procedures for carrying out maintenance tasks to determine which would be handled by maintenance technicians and which by automatic check-out equipment, under simultaneous development.

The human-factors engineer also collaborated with instruction manual writers in preparing operating and maintenance handbooks. Thus, when the project was complete, he had participated to various degrees in almost all contributing activities.

The human as a component

Human-factors engineering represents an extension of the systems design concept to include the human as a component. The entire design process is affected radically, however, because of interrelationships among components, subsystems, and functions in a system.

Acceptance of the human-factors engineer as a new member of the design team has been slow. One reason is that results of human-factors efforts are not easily measured. Testing human ability to operate particular equipment is expensive and time consuming. Time and money are seldom available for all the testing needed. Many contributions of the human-factors engineer are results of his own analysis and extrapolation from related research.

Wide acceptance of human-factors engineering today stems from the insistence of procuring agencies for operator-compatible equipment. Human-factors requirements in procurement specifications forcibly emphasize the customer's desire that careful attention be paid to ease and accuracy of operation and maintenance.

Another reason for acceptance has been the realization within engineering organizations that human-factors engineering is not merely common sense. It takes more than common sense, for example, to know the maximum noise level for operator comfort, or the maximum force a man can exert in a given situation. Man is the most complex component known, and information concerning his capabilities and limitations is voluminous. Familiarity with human performance is an invaluable asset when using man as a system component.

A different language

For years difficulties in communications retarded acceptance of human-factors engineering, and human-factors engineers have improved communications by learning the language of other specialists.

Colleges and universities now recognize this need. Many today are conducting extensive research and course work in the field, notably Massachusetts Institute of Technology; Ohio State University, which has had a laboratory of aviation psychology in operation since 1938 to train in theoretical and applied aspects of experimental psychology; UCLA; John Hopkins; Tufts; and the University of Illinois, which has a graduate program leading to a PhD in human factors. (Current projects in the University of Illinois' aviation psychology laboratory include studies of instrument flying skills, human responses in flight simulators, and the application of analog-digital conversion techniques to the reduction and analysis of human response outputs.)

Styling before safety

Human-factors engineering has made only minor progress in commercial-equipment industries. Many appliances, business machines, automobiles and trucks, etc. are deficient in terms of ease and accuracy of operation and maintenance. For example, a dishwasher manufactured by a large appliance firm has a dial located on the front of the washer to set up the washing cycle. If the dial is turned clockwise instead of the normal counter clockwise direction, the washer motor will short cut. Moreover, the dial is about 24 inches off the floor, exposed to small children.

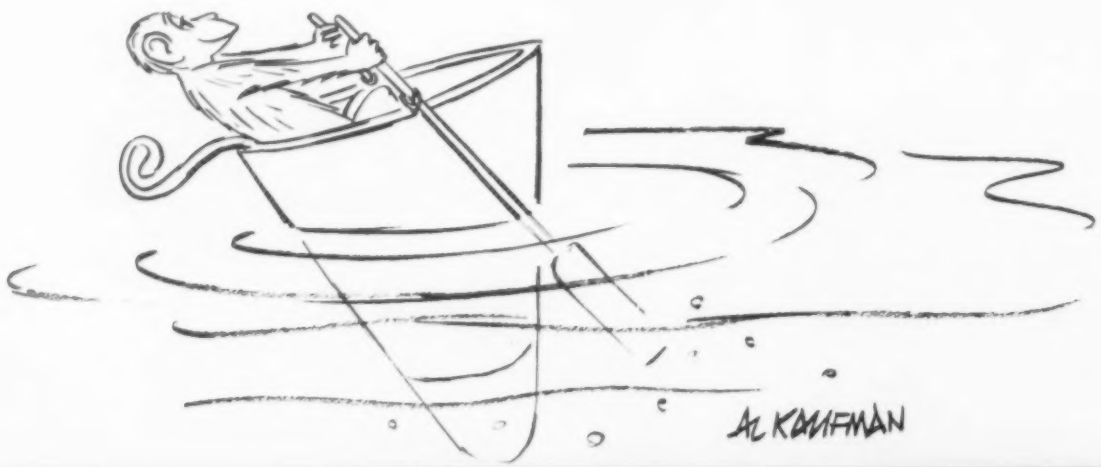
Most business machines are designed primarily for sales appeal; operation and maintenance seem to to be secondary. This situation is likely to continue until customers demand more functional designs. The automobile industry is beginning to heed the human aspects of design. Safety features are advertised widely. General Motors now has a human-factors group in its styling division at Warren, Mich.

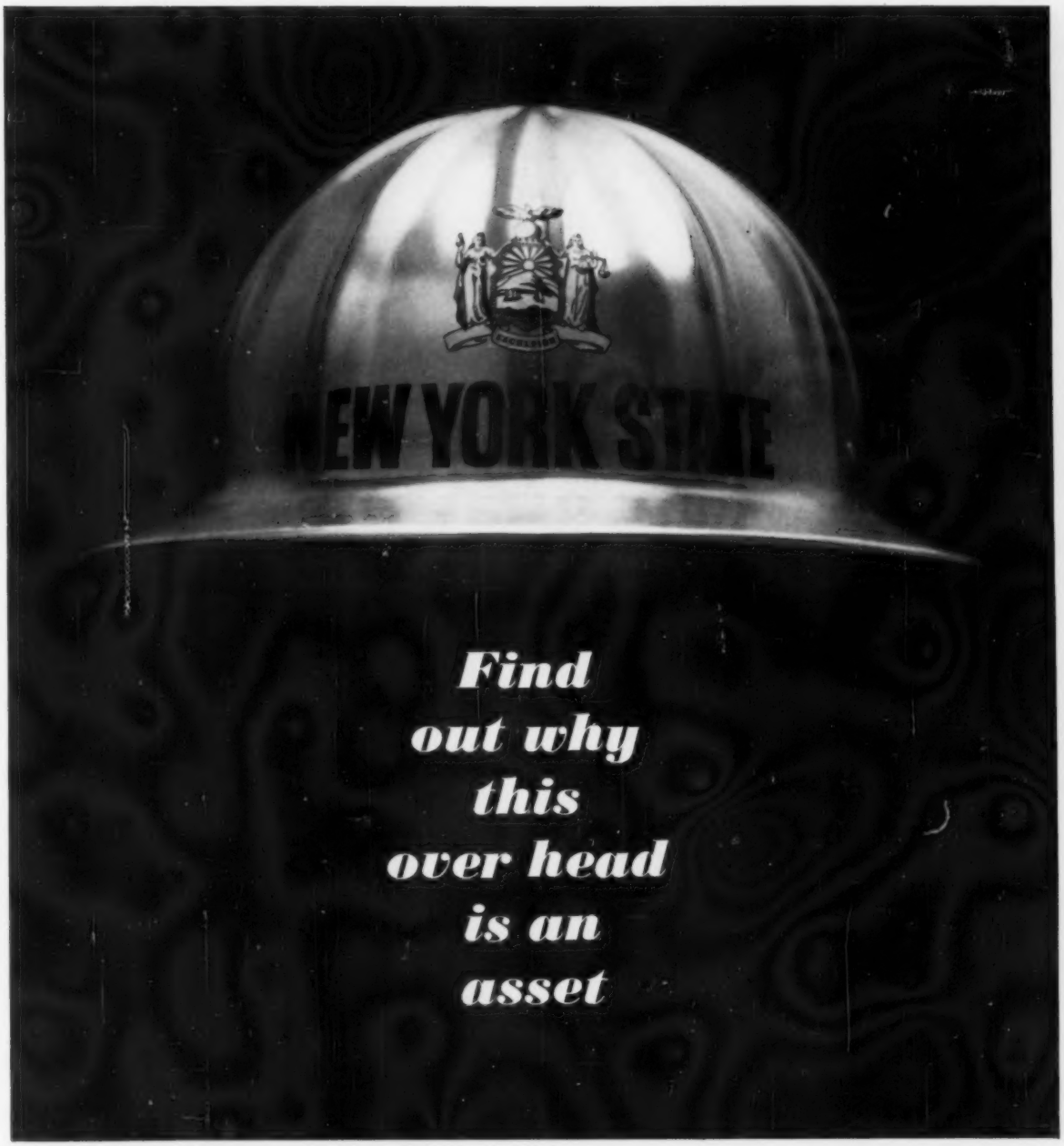
Missile and space operations are certain to accelerate the growth of human-factors engineering. The human in these areas is limited at every turn. In space, man will be subjected to high-acceleration forces; extremes of pressure, temperature, humidity, radiation, noise, and vibration; weightlessness; and loss of orientation. Means to keep the space traveler mentally sound, physically strong, and emotionally stable must be found.

Ground-support operations related to missile and space operations will continue to provide more problems for the human-factors engineer. Never before in history have requirements for human performance been so great. With the acceleration of man-in-space operations, these requirements will become even more severe.

As knowledge of human-factors engineering increases among the general public, increased applications can be expected in commercial-equipment industries. The automobile industry is likely to lead the way, followed perhaps by the agricultural machinery industry.

But progress of human-factors engineering in industries developing commercial equipment generally will remain slow. Styling, rather than operation and maintenance, is likely to dominate for a considerable time to come. Yet, the two need not be incompatible. ■





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BOEING SUBSIDIARY

by **Dr. Vincent Salmon** *manager, sonics section, Stanford Research Institute*

1: the industrial uses of sound

BECAUSE INDUSTRIAL ACOUSTICS is not as yet a well-defined activity, estimates of its size vary. The annual dollar volume of pertinent equipment manufactured in the United States is probably in the $60- 75-million range. Most of this is in sonar, underwater telephone, and fathometer devices. Equipment for other purposes accounts for scarcely $20-million, most of which is for flaw detection devices. But developments are coming so rapidly that these figures may be out of date when printed. Much of the expansion is in nonmilitary applications, especially those involving energy for industrial processing.

In sonic processing, the desired effects usually depend on cavitation—that is, the generation of shock waves by rapidly collapsing bubbles in a liquid.

Testing with sound: destructive, nondestructive

Sonic testing may be destructive or nondestructive. The necessity for the destructive testing arose in part from damage to early jet aircraft caused by intense noise from improperly located engines. This noise also can cause mal- or non-function of electronic gear. The test problem is to recreate jet noise of the desired intensity and frequency range without a jet engine. At present, sirens and modulated airstream loudspeakers (a mechanical version of human voice production) are employed, but neither are completely satisfactory. What is needed is a device with the efficiency of a siren and the ability of a modulated airstream loudspeaker to deliver several frequencies simultaneously.

Nondestructive testing is concerned with uncovering such properties as the strength of adhesive or welded bonds, viscosity, elastic constants, or grain size. The major application is the location of flaws in solids. Here, the principal sonic parameter is wavelength, for when the wavelength is much larger than the flaw, the wave is unaware of the presence of the flaw. For the flaws of industrial interest (in metal parts), this usually means that ultrasonic frequencies are necessary. For example, to delineate defects larger than $\frac{1}{8}$-inch extent in steel, the frequency of the probe wave should be over one megacycle per second (one million cps). Ordinarily, compressional pulses of the sound are transmitted, and the instrument "listens" for reflections from defects. The

time of transit to and from the defect locates it. Many such devices are on the market, but are hard pressed when the flaw is close to the source of the ultrasonic pulse. In this case, the echo may return while the transmitted pulse is still continuing and thus may be hidden in the transmitted pulse. At present, pulse-echo devices using some species of surface wave appear fairly promising in the inspection of near-surface flaws. The precise type of wave used depends on whether the flaw is laminar (parallel to the surface) or a crack (perpendicular to the surface). Operating difficulties remain, and we shall have to rely on further research for an answer.

Exciting the polymer

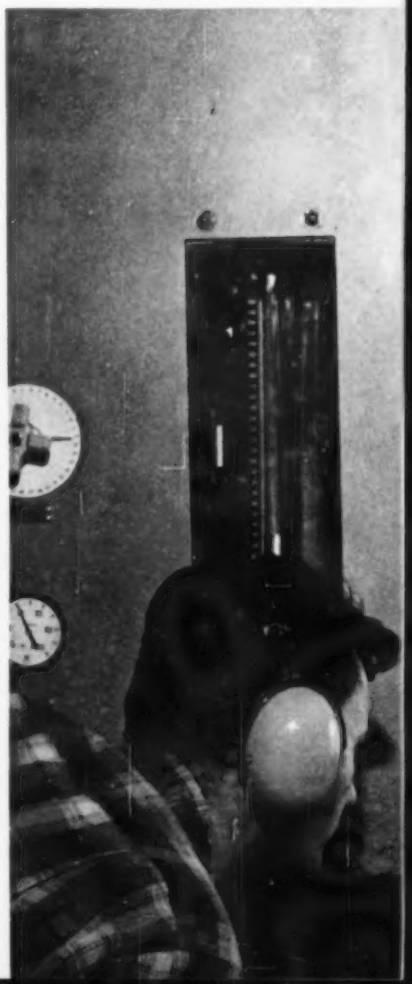
The elasticity of a material depends on both the constitution of its structural elements and how these elements are assembled. For example, in a polymer both the elastic properties of each molecule and the degree of crosslinking between molecules control the overall elastic properties. Usually these properties must be described in terms of energy storage and energy loss, under the general heading of viscoelastic behavior. These properties can be measured with sound. Such tests are commonplace in the elastomer and textile industries, and often serve in production control as well as in product development. The extension of similar sonic testing techniques to problems in ceramics, glass, and metals technology is but a matter of time. Even our present limited probing in space-flight environments has exposed some severe problems.

An important example of nondestructive testing is the location of sizable foreign objects in a large body of liquid, as a lurking submarine. We know this technology better as sonar, but in principle it utilizes much the same equipment as that used in the laboratory for pulse-echo ultrasonic defectoscopy. However, the defect now may be tens and even hundreds of feet long, and the distances may be in miles. Instead of a stable and excellently-conducting medium, we have to deal with a restless, changing ocean that shatters sound beams, and bends and reflects them into an almost unrecognizable form. Research to overcome or circumvent these natural limitations is of prime importance in national defense. Perhaps the sense of urgency felt by many workers in sonar technology will communicate itself not only to acoustical scientists but also to researchers in the allied contributing fields of fluid dynamics, oceanography, information theory, computers, and what might be termed bathymeteorology, or "underwater weather study."

Almost everyone has run into situations for which nondestructive tests would have prevented dangerous or unpleasant results. The ripe egg in the frying pan, the fermenting canned fruit, the windshield that dissolves at the first pebble strike, the knothole that may appear when plywood is cut, the welded Liberty ship that cracks in two—all of these involve defects that may possibly be located by sonic testing.

Sound has been applied successfully to the measurement of liquid flow in pipelines, using the fact that the motion of the medium changes the apparent sound wave velocity. Still, there does not exist a general-purpose portable, sonic flowmeter that can be clamped on a pipeline quickly. The chief difficulties lie in turbulent flow in the pipe and transmission of signals in the walls of the pipe, rather than in the liquid.

With a modified sonic instrument, the spacing between fixed and movable objects may be measured. Such devices should have all sorts of application where dial or feeler gages now are used; for example, the eccentricity of rotating parts can be measured easily. Or a sonic altimeter could help helicopters land or maintain a fixed altitude above, say, a heaving sea. A similar device, horizontally directed, in automobiles would serve to indicate the distance of the car ahead in heavy traffic or dense fog.



REMOVING FOAM *from liquids is an application of sound in industrial and chemical processing. Pressure from sonic and ultrasonic waves transmitted through air induces resonant*

Vincent Salmon began research studies in acoustics even before receiving his doctorate in 1938. During the war he designed electroacoustic equipment for combat ships to withstand severe aerial or underwater shock waves. He also contributed to radar countermeasures. Since joining Stanford Research Institute in 1949, much of his work has involved applications of sound and vibration phenomena to industrial testing, processing, and control. Other studies have been related to noise reduction, modulated airstream loudspeakers, and ultrasonic food processing. Currently, he is manager of the sonics section at SRI.

Changing the chemical reaction

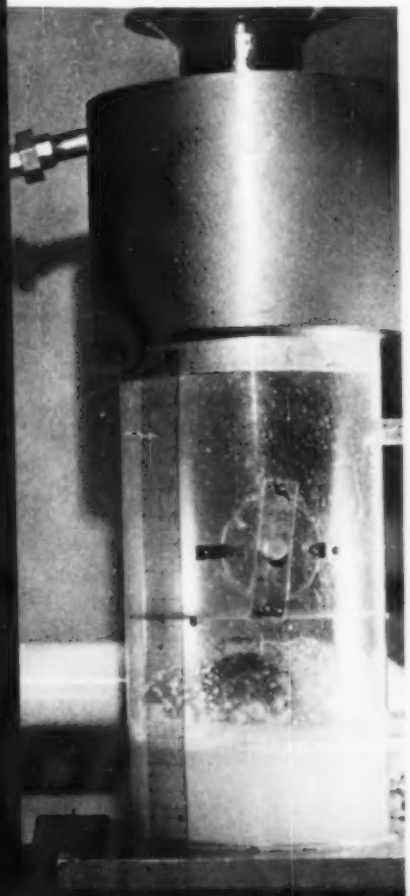
Much of sonic processing involves working in a liquid medium with sound intense enough to produce cavitation. As explained, this action results in the repeated production of intense short-range shock waves, which in turn are responsible for many of the effects observed. Cavitating sound can cause chemical reactions to begin or to proceed faster. Thus, controlled chemical attack on hard metals, known as chemical milling, can be speeded. Indeed, with proper direction of the sound beam, the chemical attack possibly may be made more selective and controllable.

Intense cavitation can rip apart long molecules. Thus, enzymes can be deactivated, and liquids having a large range of high molecular weights can be reduced to smaller molecular weights. This has primary application in finishes such as lacquers and varnishes, where the film-forming properties are improved by molecular weight control. However, no large-scale exploitation of this application of sonic processing has been tried yet, probably because of the high cost of the sonic energy.

An interesting application occurs in the extraction of fat from bone meal in the manufacture of glue and gelatin. Ordinarily, hot solvent extraction is used, but the extraction is incomplete, and the end product may be degraded by heat. Cavitating sound has been found to effect more complete separations at temperatures low enough so that the fat is unharmed. But the cost of sonic energy generated by conventional means is so great that it is infeasible.

One important chemical effect lies in the apparent ability of intense sound to control combustion. The glamorous example of the moment is the increase in burning rate occurring in solid-fuel rocket motors where intense self-generated oscillations can build up, sometimes until the motor is destroyed. With controlled use of this effect, we may be better able to direct rockets or to obtain more energy from oil burner flames. Research is barely getting under way, and 1961 may see the first concrete results.

vibrations in the bubbles and squeezes them so they collapse in a few seconds. Such generators also are used for drying, particle agglomeration, and environmental testing, at Gulton Industries Inc.



Sound — an effective cleaner

Physical effects of cavitating sonic energy are best typified by the many sonic cleaners on the market. In these cleaners, tiny, intense shock waves caused by cavitation literally blast the soil off the surfaces to be cleaned. Sonic cleaners provide expensive energy, and hence are most feasible where the piece part cost is high. Ball bearings, instrument bearings, gyros, hypodermic needles, and shaver heads are typical examples. Effective application of sonic energy to home dishwashers and the like does not now appear promising.

Watch cleaning is a good example in which sonic cleaners probably will supersede others. The watch may be cleaned, without disassembly, much more thoroughly than by conventional means. The decreased handling also means less chance of damaging the delicate works.

The sonic cleaner industry is gradually divesting itself of the emphasis on ultrasonic energy, for better effects are often obtained at audible frequencies. A major unsolved problem is how to specify cleaning efficiency or even intensity of cavitation. At present we do not even know what questions to ask, much less the answers. But the problem has been recognized.

Cavitation has been used in a demonstration of the emulsification of mercury and water, a laboratory curio only. Cavitation-induced shock waves shatter the mercury into very fine droplets that remain suspended for a relatively long time. Ordinarily, the energy costs too much for such mundane tasks as homogenizing milk or making mayonnaise. Probably sonically-produced emulsions will always be a laboratory accomplishment, and industrial applications will be only for the really difficult tasks.

A physical effect of cavitation that is of industrial importance is the increased

transfer of heat through a liquid-solid interface. The sound produces an intense stirring action that is concentrated at the interface, and the heat transfer rate may be increased by 200 to 300%. There is potential application to heat transfer in nuclear reactors, where the local heating problem on fuel elements is still incompletely solved. However, large amounts of sound are needed, and as yet we do not have inexpensive sources.

Sound in metallurgy

In metals technology, the use of intense sonic energy during the solidification of a metal from its melt will prevent the coarse, tree-like structures called dendrites. The final metal grains are small, and more of the resulting casting is sound. A Czech firm is rumored to have a sonic casting process in operation; it should be particularly useful in casting turbine buckets and other high-cost, high-performance parts. Isolation of the sound source from the heat of the melt is perhaps the largest problem. However, there is really no research uncertainty, and only straightforward engineering is needed to make the process practical for small, expensive parts.

Action of sound waves is greatest at the corners of a solid object when it is immersed in a liquid. This fact is being used in sonic deburring of cast or machined parts. The parts are immersed in a stirred abrasive slurry supplied with cavitating sound. Edges are speedily removed, with minimum change of critical dimensions. There should be all sorts of applications of this idea, which at present is restricted to small, expensive parts because of cost.

Acoustics is a rapidly growing business, particularly in

to measure liquid flow, measure distances, make chemicals

VARIETY OF SOUND AND ULTRASOUND *equipment includes everything from the ultrasonic impact grinder (above), and the communications microphone (undergoing tests at left), to the stereophonic playback system (below). The grinder, a Raytheon product, is shown being used to slice wafers of quartz for radio crystals. Such hard or brittle materials can be cut to tolerances of ±0.0003 inches. An engineer is testing the microphone in a room at Shure Brothers Inc., where very high intensity sound can be generated. A pickup cartridge in the stereo system is being given a final inspection in the factory (also at Shure).*

Sonic impact grinding involves the vibratory motion of a tool to drive abrasive diamond chips against a hard, brittle material. Thus, die cavities can be sunk in very hard metals, or glass can be cut in intricate designs. Use of sonic impact grinding is now firmly established, and efforts have been made to apply it to dental drills. The misnomer, "drilling with sound," has led to some disappointment, for the drilling is done by the abrasive, which must be continuously fed in and removed from the mouth. Also, there is an unresolved controversy as to whether or not the repeated impacts will damage tooth pulp and nerve tissue. The most that can be said is that good, objective, quantitative evidence for one view or the other still is needed.

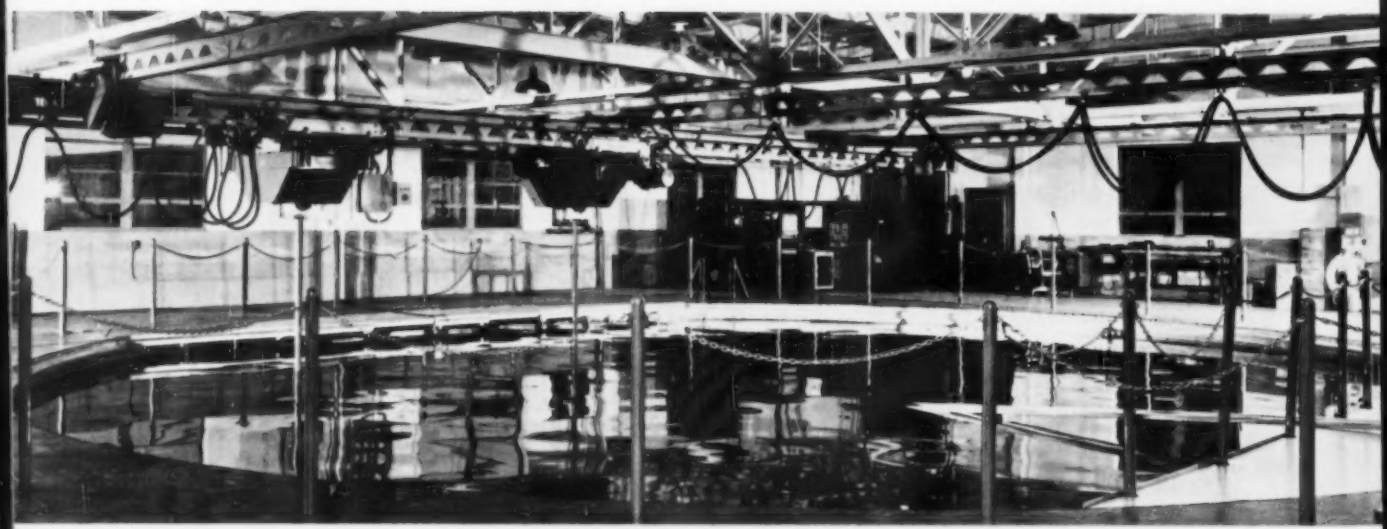
In forming metal in a die, considerable wear of the die walls occurs. It has been proposed to vibrate the walls of the die so that the metal will flow more easily, as does flour in a vibrating chute. The idea has not received a fully definitive test, but it seems likely that some useful effects should be obtained.

The man in the white suit

In textile production, one of the most fabulous fibers is the product of the oriental plant, ramie. Its stout fiber produces such long wearing cloth that even the Man in the White Suit would raise his eyebrows. Socks lasting 20 years have been claimed, though the proof is rather tenuous. Production of the ramie fibers is hampered by their affinity for the other portions of the plant. Ordinarily, retting (exposing the plant to the action of the elements)

nonmilitary applications. Sonics and ultrasonics can be used

process materials, clean or drill parts, and control bacteria growth.



UNDERWATER ACOUSTIC *test facility (above) at Stromberg-Carlson, the nation's largest, is used for studies of sonar, underwater sound transmission properties, and propagation of sound from air into water. Another novel test facility, the plane wave tube (right) of Altec Lansing, has several drivers in a tree-like arrangement. The tube produces a high-intensity plane wave for testing small parts and assemblies.*

is used to separate fibers from the other plant material. However, the treatment weakens the fiber. It would seem that cavitation attack, in combination with chemical treatment, might hasten the process without undue damage to the fiber. At present there is no economic necessity for this material, so the idea has had no full and careful investigation.

Cavitating sound increases the flow of liquids through semi-permeable membranes. Thus, intense sonic energy might well dramatically decrease the time required for tanning leather. Again, the optimum tanning substance would not necessarily be the same as those used in the conventional process.

In food technology and pharmaceuticals, sonic processing already has been used on a small scale. Below the cavitation threshold, sonic agitation has increased the rate of bacteria growth by a factor of 50. However, above the threshold, the cell walls are ruptured, killing the microorganisms (or human cells) in the treatment zone.

Needed — cheap sound

In all the foregoing processing applications of sonic energy, a large obstacle to their full exploitation is the absence of a suitable, economical sonic source. Such a source should yield high power with good efficiency, should have low installation and operating cost, should be serviceable by a plant plumber and electrician, and should be suitable for flow processing. No present sonic generator satisfies all these requirements.

The need for a cheap high-power device has prompted an examination of the difficulty of producing cavitation as a function of frequency. In water, below a frequency of 10,000 cps, a relatively constant amount of energy suffices, whereas above this frequency the energy requirement increases sharply. Working below 10,000 cps loses the magic appeal of ultrasonics, but gains the use of rotating machinery to produce the energy. Compact, 30 kilowatt, 10,000 cps motor-generators are readily available. Such a power source should be more attractive than a vacuum tube supply.

Another possible improvement in means of producing intense sonic energy is the replacement of magnetostrictive and ferro-electric (ceramic) devices by purely mechanical ones. A possible high-power source now being developed employs the same mechanism as a water valve that screams; it uses a motor, a pump, and a special valve. Called a hydrodynamic oscillator, it may well make possible a host of applications that await such a simple source.

For operation at frequencies below 1000 cps, unbalanced rotating mass force generators are available. Some are capable of acoustic outputs in excess of 100 hp when properly coupled to the liquid. Finally, in a fluid modulator, the steady stream of liquid from a pump can be changed into a pulsatory flow; this energy can readily be piped to the point of use. All these ideas are being investigated now, and should one turn out to be the answer, sonic processing should become a standard tool for industry.

Sensing a change and acting upon it

The use of sound waves for control involves an instrument's sensing a change and acting on it. Here we shall briefly mention a few. A popular TV remote control uses struck bars to produce ultrasonic control signals. A garage door opener employs an ultrasonic whistle operated from the car's intake manifold. Guide canes for the blind use reflections of short-wavelength sound to locate obstacles such as curbs. And an inaudible burglar alarm uses criss-crossing sound waves that detect any motion in their field. This device also detects flames and mice; the latter sensitivity had to be thwarted by a "mouse recognition" circuit. Finally, a system of sonar beacons have been suggested to replace lighthouses and foghorns. All of these control uses of sound are relatively straightforward, and need more ingenuity than research.

by **Amos Picker,** *physicist, Stanford Research Institute*

2: the laboratory uses of sound

TO THE EARS OF A PHYSICIST the most exciting sounds are the unheard cacophonies of agitated atoms as they vibrate around their almost fixed positions in the scheme of the solids, liquids, and gases they constitute. By "listening" attentively to the atoms and by interpreting their message, the physicist can learn to make stronger metals, magnets that are more powerful, better transistors, or wire with less resistance. Or he can possibly devise means of telling when an aircraft wing is ready to crack and fall off.

To perceive this "song" of the atoms, and indeed to influence it as well, the physicist probes matter with beams of sound. Physical acoustics is the study of the interaction between the sound in the probe beam and the vibration of atoms. The worker in physical acoustics relies on measurements of both sonic velocity and sound absorption to obtain information on atomic events.

How atoms move

The ability of a material to absorb sound depends on the arrangement of its atoms. On a per-atom basis, hot gases absorb strongly, whereas a perfect crystal at absolute zero attenuates sound only slightly. Absorption of sound in gases results from a number of mechanisms. The important ones are the internal friction or viscosity of the gas, its ability to conduct heat, and its conversion of heat to other forms of energy.

Of these mechanisms perhaps the most fascinating is the conversion of heat. As set forth in high school physics, heat is nothing more than the energy of random motion of molecules or atoms. But complicated molecules may have internal motions of their component atoms. Take for example the carbon dioxide molecule, with its central carbon holding apart the two oxygen atoms at "arm's length." Of the internal motions possible, three are quite interesting. The two oxygens may move as would the wings of a bird; or, with the carbon still fixed, the oxygens may together approach and leave the central carbon in a back-and-forth motion; or, with the oxygens fixed, the carbon may shuttle back and forth between them.

For all of these motions, a finite time is required for the build-up of the vibration, as well as its later decay. The repeated impacts that a sound wave superposes upon random motion furnishes a means of exciting the internal vibration of the molecules. When the frequency of the sound waves introduced into a gas is properly related to the time for build-up and decay of the internal molecular vibration, a point is reached at which maximum absorption of the sound takes place. Thus, from measurements made at various sonic frequencies, it is possible to learn something about the way that impact motion is transformed into internal vibration of molecules. Ordinarily, this transformation is infrequent; over 500,000 collisions of CO_2 molecules are necessary to produce one pair of molecules in which the energy of impact is transformed to the energy of internal vibration.

By use of impact-motion studies, it is possible to ascertain the effects of small amounts of impurities in a gaseous mixture, because such impurities can markedly change the frequency at which the attenuation per wavelength reaches a maximum. Such a sonic gas-analyzer is at present only of laboratory value because of the availability of simpler but still satisfactory means for determining gas composition. However, when precise results are needed, and the general nature of the purity substance is known, very sensitive analysis can be obtained by this procedure.

Sound beams are bei

Sound for chemistry

An additional possibility exists in what might be called sonic catalysis. Conceive of molecular reactions that proceed slowly. Often these can be facilitated if the molecule is put in an excited state. Such a state corresponds to violent motion of the component atoms. This motion, of course, corresponds to the internal modes of vibration which in turn can be excited by sound of the proper frequency.

Sonic catalysis may have value in survival under conditions of a closed ecology (space ships, true submarines, and fall-out shelters). There, the conversion of atmospheric carbon dioxide back to carbon and oxygen will constitute an important problem. If the proper impurities are added to the carbon dioxide, together with nascent (atomic) hydrogen, excitation by sound of the proper frequency possibly might cause a reaction resulting in water and elemental carbon. The added impurity may well be water vapor, which reduces the amount of collisions necessary for transfer of energy from 670,000 down to 40. This method of sonic catalysis probably can be extended to other gaseous reactions that otherwise would go slowly or not at all.

Gaps in liquids

When sound is used to probe the properties of liquids, we are faced with the fact that there is as yet no completely adequate theory on which to base interpretations of experimental findings. We do believe that a liquid is a sort of crystal in which restless motion is present at all times. A liquid also contains unfilled spaces which account for a great deal of its mobility. When a liquid is compressed, several actions occur that correspond to a decrease in external volume. We can simply decrease the average spacing of the molecules, but also can rearrange the structure for greater compactness in much the same manner that a haphazard pile of cannon balls can be stacked in a neat pyramid. The times in which the decrease of spacing and rearrangement of structure takes place may be quite different. By using sounds of different frequencies, the mechanism of each type of compressibility can be studied.

In many chemical reactions in liquids, the reaction rate depends upon the pressure. Since sound is a periodic pressure change, reaction rates in liquids can be altered by the presence of sound. Indeed, the absorption of sound under such conditions can be a measure of the reaction rate involved. Sea water

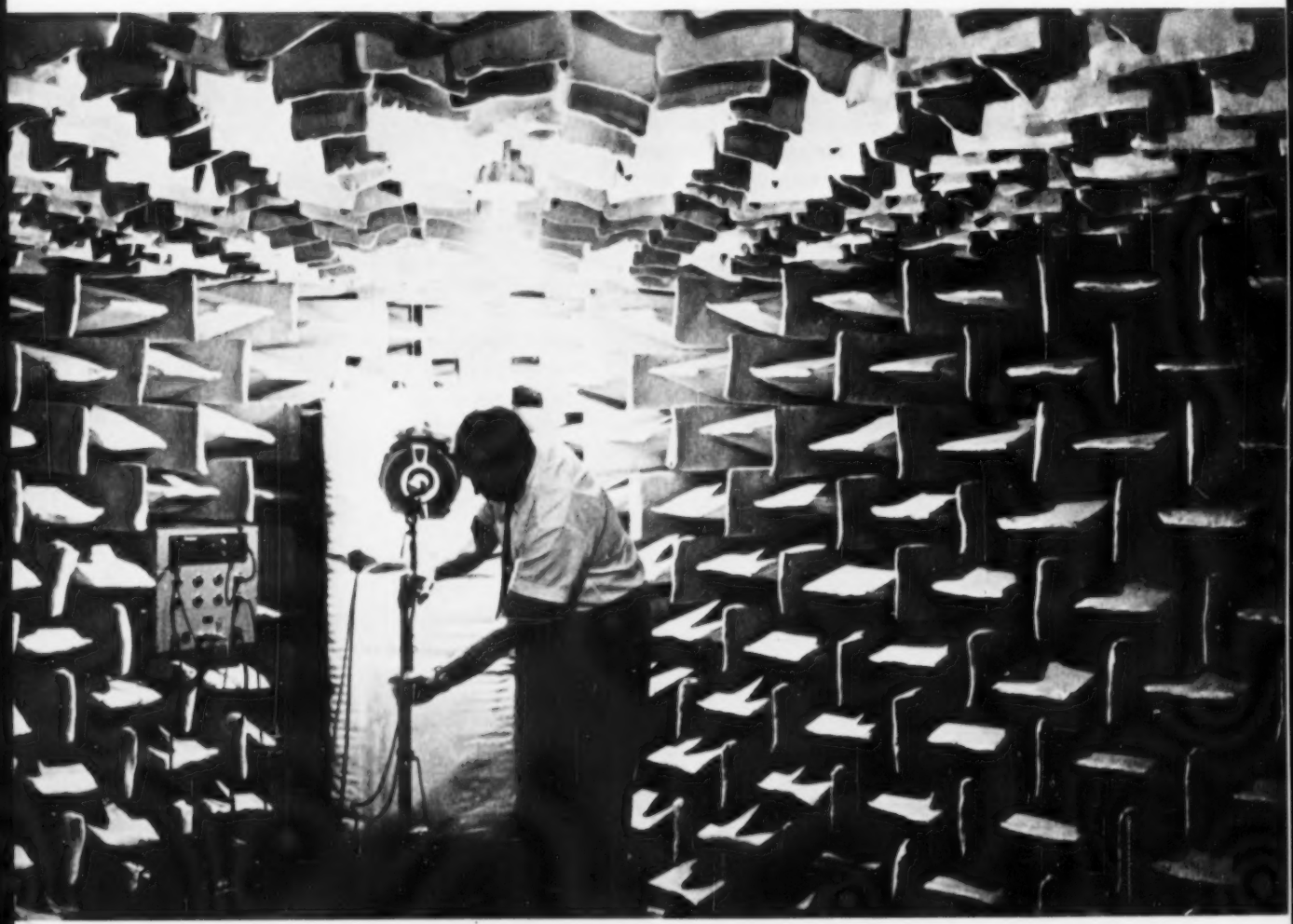
Since joining Stanford Research Institute in 1959, Amos Picker has been engaged in the development of airstream modulators and has carried out theoretical work on acoustical fields and impedances of systems in liquids. He attended Hebrew University in Jerusalem and received the ScM degree from Brown University. While at Brown, he did research on theories of metal dislocations, metal fatigue, and diffusion in crystals. Picker is a native of Israel.

contains substances having pressure-sensitive reaction rates, thus contributing to the absorption of sound therein. Workers in such frontier fields as liquid thermoelectric materials and pressure-sensitive chemical reactions will find that an acoustical probe beam can supply basic information not easily available otherwise. It does not take too much imagination to conceive of means of monitoring industrial reactions by sound, the absorption of which can be used to indicate the reaction rate.

Predicting fatigue failure

Sound is absorbed in solids in several ways, of which the most important is dislocation. Imagine a perfect crystal in which all atoms are in a regular array. Now, if an external force is applied that can tear away one group of atoms from another, a deforming or twisting of the atom network may result. If this produces a sudden break in the regularity and a new type of regularity con-

g used to probe the secrets of molecules, a step toward better materials.



ANECHOIC ROOM, *or echo-less room, is an essential facility of many organizations studying sound phenomena. Sound waves entering spaces between the wedge-shaped, sound-absorbing material are reflected from side to side and dissipated. This room, at Shure Brothers, is being used for microphone measurements.*

tinues beyond the break, the position of the break is called a dislocation. When dislocations grow in size they eventually become physical cracks, and thus are the primitive cause of failure by fatigue in metal parts.

Absorption of sound in a metal in which dislocations have been grown by repeated alternating stressing might be used as a measure of this stressing. Therefore, we can use this to design nondestructive means that will indicate the state of cumulative fatigue. Such a development would be extremely important in modern aircraft and space ships where there is a constantly increasing demand for lightweight, but safe, metals.

Absorption of sound in metal also arises from a stressed network of atoms in a crystal owing to the presence of a foreign atom which is not the right size to fit. In addition, atoms or electrons displaced from their assigned sites either by externally applied forces or by nuclear radiation also enhance the absorption of sound. Subsidiary phenomena contributing to absorption include heat conduction, viscous effects at grain boundaries, and various elastic effects.

Another phenomenon by means of which sound is absorbed is scattering. When the wavelength of the sonic probe beam is comparable to the size of the crystallites (grains) in the metal, sound is deflected rather than transmitted straight through. This sound, appearing at right angles to the probe beam, may be taken as a measure of that which is scattered and hence is a direct measure of the grain size of the metal. Thus, grain size can be determined in a rapid and nondestructive fashion. There are certain practical difficulties in putting this concept to work, but in its ultimate form it would provide a rapid means of determining the state of heat treatment.

Molecular circuits

The action of many semiconductors depends upon the diffusion of atoms of different types or of different elements. Sonic energy of the right frequency and intensity may facilitate diffusion of selected impurity atoms to the proper site within a semiconductor, thus making it possible to develop very tiny transistor and other semiconductor devices for "molecular circuits." The sonic frequencies necessary for maximum effect are at the extreme end of our capabilities, but in principle all that is required is a suitable generator.

Such a generator recently has been developed. It produces sound waves with frequencies as high as 100,000 million cycles per second by using a combination of techniques. Imagine a microwave resonator in which very high electrical fields are generated across the face of a quartz crystal placed at the appropriate part of the microwave generator. Ordinarily these waves would be absorbed very rapidly. However, at sufficiently low temperatures, a sort of acoustic superconductivity occurs, in which the absorption of sound decreases dramatically. Below this critical temperature, mechanical waves with appreciable energy are generated, and thus provide the source necessary for the semiconductor experiments mentioned.

At present, the basic scientist is most intrigued by these ultra high frequency sound waves because they allow him to explore the essential processes by which heat is transferred within a material. In addition, electrical effects can be investigated by the interaction between the sound and the electrons responsible for the conductivity of electricity. Thus, we have almost in our grasp direct means of exploring events on an atomic scale, or, by quantum transitions, perhaps on a nuclear scale.

This information is far from any immediate application to industrial problems. Nevertheless, it is on such research that industry of the future must lean. One of the first tangible results may well be a better understanding of the factors determining the strength of metals. Once we have this information, we should be able to make structures that are much lighter and stronger. ■

by **Dr. Hubert Frings** *and* **Mrs. Mable Frings,** *professor of zoology and research associate in zoology, Pennsylvania State University*

3: life sounds and communications

THE CALLS AND SONGS OF THE ANIMAL WORLD have attracted man's attention for centuries. Amazingly enough, however, only 25 years ago, many scientists seriously maintained that insect songs, for example, were no more useful to the insects than snoring to man. They could not find ears on insects where they expected to find them, and so they thought them deaf. Modern techniques for recording and broadcasting sounds and unbiased studies on behavior have shown conclusively that insect sounds, like vertebrate sounds, are purposeful and can be heard by other insects. Modern equipment for picking up underwater sounds also has led to our being able to tune in on our underwater neighbors. In short, animals of all sorts are using sounds to communicate with others. Therefore, we can begin to ask whether sounds could be used to call in desirable animals or to repel the unwanted.

Selective communication

All animals produce sounds, if only in moving or feeding. But these sounds may be incidental and of no significance in their lives. After all, you can't chew celery without making a noise, even if the noise has no significance otherwise. We must always be careful, however, about relegating sounds to the level of insignificance just because—to us—they seem to be incidental to some other activity. The whine of the female mosquito, as her wings pulse the air, is an unavoidable accompaniment to her flight. But it also is heard by the male, and he is induced to chase and mate with her.

Many animals produce sounds voluntarily. Dogs bark, birds sing, reptiles hiss, frogs chorus, fish croak, crickets chirp, beetles squeak, shrimp snap, to mention only a few. In all these, special organs are developed, often extremely complex, to produce the sounds. Certainly, one must expect that these sounds are important to the animals. And we now know that they are. The calls of mammals, such as cows, horses, dogs, and mice, keep them in touch with their fellows. The cries of bats enable them to "see" by ear in the dark. The songs of birds proclaim their territories. The trilling of male toads and the

chirping of male crickets call females to assure continuation of the species.

Biologists, now armed with tape recorders and analyzing equipment, are studying these sounds. For mammals, we shall mention only two of these studies, because they illustrate some of the problems in this work. Marine biologists have recorded sounds produced by whales and porpoises. In porpoises, the sounds have been shown to be sonar signals, allowing the marine mammals to avoid obstacles. In whales, the uses are still conjectural. How they do it without bubbling air is a mystery.

Bats use very high frequency sounds as a type of sonar also. By sending out pulses of these sounds and determining the time needed for them to return, they can locate obstacles and food. This has been called echolocation. Each species of bat seems to have a characteristic signal, and the production of highly rhythmically structured sounds at very high frequencies (two to three octaves above the upper limit for human hearing) requires very special vocal and focussing equipment. Bats are famous for their grotesque faces, and it is certain that this grotesquerie is involved in their echolocation. So far the studies on bats have been entirely fundamental, but jamming the sonar system of bats might be used to keep these ordinarily useful mammals from places where they are not wanted.

Hubert and Mable Frings have worked in biological acoustics research since joining the staff of Penn State University in 1947. Working cooperatively since then, the Fringses have studied effects of high intensity sounds on animals, beginning with mice. Observing that sounds might be useful for insect control,

Insect transmitters . . .

Insects produce sounds in many ways: thumping, grinding the mouth-parts, snapping spine-like projections, snapping vibrating membranes, expelling liquids through pores, vibrating their wings or body-wall, and, most commonly, scraping toothed ridges together or against various parts of the body (stridulation). The sounds they produce are equally varied in frequency, intensity, and rhythm.

Many insect sounds consist of short bursts, with sudden onset, as a result of snapping or scraping. These sounds, because of the small size of insects and presence of specialized vibrating areas, may be ultrasonic to us. Autumn evenings, then, are much more noisy with insect sounds than we can appreciate.

Since insects adopt the temperature of their environment, their singing rates change with temperature. Interestingly enough, the females that receive the sound messages from their wooing males alter their responses with temperature correspondingly.

. . . and insect receivers

While no one has ever seriously doubted that higher animals hear, many have argued that animals without obvious ears, such as insects, do not. When these animals were shown to react to sounds, their critics took refuge

PHYSIOLOGICAL *instrumentation facility at the University of Chicago is used to study hearing in animals. Threshold intensities, frequency ranges, and response to electrical stimuli of cats, guinea pigs, and monkeys are measured under different environmental conditions.*

they undertook investigations of insect acoustics, still a major interest. They were the first to develop and use recorded distress calls for repelling starlings, and later for gulls and crows. Two years ago they went to Midway Island in the Pacific to help the U.S. Navy solve a problem of troublesome albatrosses.

in the belief that they really reacted to vibrations.

Actually, sound is sound, whether it reaches an animal through air, water, or solid, and most animals can receive sounds coming by all these routes. Biologists, therefore, are coming more and more to use the terms, sound reception and sound receptors. For brevity, however, they still talk of hearing and ears, knowing these are vastly different from hearing and ears of man.

The study of sound reception in lower animals is not easy. After all, you can't just ask an insect or a bird whether it has heard a noise or not. In general, two classes of methods are used for these studies. The first uses action potentials aroused in nerves leading from sound-sensitive organs when the organs are stimulated. These tiny electrical charges are picked up from the nerves by microelectrodes, amplified, and displayed on an oscilloscope screen or recorded. It is then possible to determine whether given frequencies and intensities of sound can activate a supposed sound receptor. The second method of study uses reactions of the animals to sounds to indicate reception. These reactions may be inborn, such as jumping at a loud noise, or they may be developed by training. Usually they are visible to man, but occasionally invisible physiological changes, such as in pulse rate or skin resistance, are used.

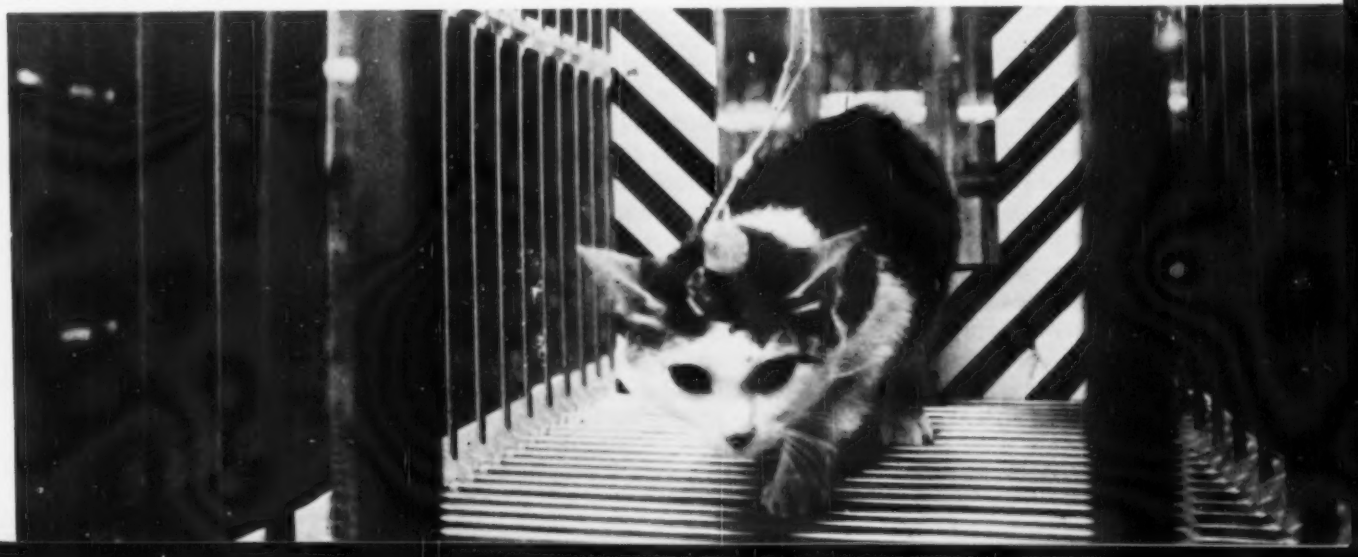
In our studies, we have found that barnacles can be caused to snap their shells closed when beeped with sounds of certain frequencies. Other workers have developed an ultrasonic vibrator for ships' hulls which, they claim, keeps barnacles from settling and thus frees ships from these drag-producing organisms. Their practical tests look promising. Still another approach might be investigated: it is not outside the realm of possibility that barnacles, which are free swimming creatures when young, may be aggregated by vibrations produced by the movements of the food-capturing appendages of the adults.

Grasshoppers detect frequencies

Crickets and the so-called long-horn grasshoppers have highly complicated ears on their front legs. These are tuned to the song of the species, but they filter out that frequency, leaving nerve impulses corresponding with the pulse rate (rate of movement of the wings with the stridulating combs on them). Other grasshoppers, the short-horns, have less-complicated ears on the abdomen, acting similarly, except that the carrier is a noise. Those noisy daytime insect musicians, cicadas—sometimes called locusts—receive the signals through ears on the abdomen, having also the ability to filter out the carrier sound frequency.

Many important crop pests are the larvae of moths. The adults fly at night to lay their eggs on host plants. What if we could, by pulsing out ultrasonic sounds, simulate a flock of hunting bats over our crops? Would moths avoid

AUDITORY CENTER *of a cat is being studied by measuring electric potentials during a learning process or exposure to sound. Electrical signals can cause physical responses similar to those for sound. Various animals hear widely different frequency ranges.*



these places? So far, practical tests such as this have not been set up, but this is a place where practical use of sounds for insect control seems possible.

Mosquitoes and many other insects can pick up sounds with their antennas, and analyze the antennal vibrations with a complicated organ at the base of the antenna—Johnston's Organ. Since 1874, biologists have known that mosquitoes are attracted to buzzing noises. Only males are attracted, and the sounds must be at frequencies like those of the female wing sound. Studies have been made in which male mosquitoes were attracted to their death on charged grids by playing recorded female wing sounds to them. Unfortunately, males do not bite and therefore do not carry disease; only females do. A single fertilized female mosquito can lay hundreds of eggs, and generally most young mosquito wrigglers die for lack of food. In short, just a few females can supply all the population needed, and it is impossible to get all the males by sound.

In our opinion, attraction offers little hope for effective control for insects such as mosquitoes or houseflies. Any artificial attractant must compete, under adverse circumstances, with the natural attractant, and the ability of these insects to produce myriads of offspring defeats the purpose. However, a sonic repellent—particularly if the sound were ultrasonic for man—could really be useful to wall off a given area, such as a patio, canoe, or beach, from pests.

The special sound-receiving organs of insects are sensitive to extremely low sound intensities, and often are tuned with amazing nicety. Yet the basic units involved are remarkably few and have remarkably similar reactions among all insects. In short, the coding system for information is quite simple. We might very well learn a great deal about sensitive receptor devices and informational coding by careful studies of the means by which insects convey messages by sounds. Through such study of biological systems, we may be able to improve man-made instruments for coding—for example, computers.

Supersensitive strain gages

So far, we have discussed only two types of sound receptors of insects. We can just mention some others briefly, noting that most insects, even those with special ears or antennal receptors, have two or three of these at least.

In the joints of the legs of most insects there are sensitive nerve-endings, acting like strain gages to pick up movements, particularly vibrations of the surfaces on which insects stand. These are almost unbelievably sensitive, and are quite necessary organs for early warning of enemy approach. Movements of the leg of the cockroach as small as 0.01 millimicron (1/2,540,000,000 in.) produce potentials in nerves leading from these strain gages. Honey bees can be made to stop moving their legs by vibrations as small as 0.05 millimicrons. These vibration receptors are at just about the limit of sensitivity. Were they more sensitive, they would be stimulated by movements of the molecules in the insect's blood!

The bodies of insects are clothed with many types of hairs and bristles sensitive to movement. While these usually are used to notify the armor-plated bugs of objects that touch them, they also are moved by sounds, if the intensity is high enough. Moths with their ultrasonic-sensitive ears destroyed still respond to sounds of lower frequencies, and these reactions are probably triggered by movements of such hairs. Still further, muscle stretch receptors and special thin areas in the insect's external armor that are stretchable and pull on attached sense cells also are involved.

Is it any wonder that, with this battery of sound-sensitive organs, insects can so successfully escape their enemies and find their mates? Have you ever asked yourself, when some tiny mite of insect life flew in to a light in your home, how so small a being found another one equally small in a world that, to it, would be so infinitely vast? Odors, yes—and we know much about

ULTRASONIC DEPTH *sounder is used to chart a lake bottom by Maine's Dept. of Inland Fisheries and Game. More than 1,000 lakes have been surveyed to provide data for improving fishing opportunities for sportsmen. The ultrasonic equipment (made by Raytheon) finds water depth, bottom texture, unseen obstructions, and fish lairs.*

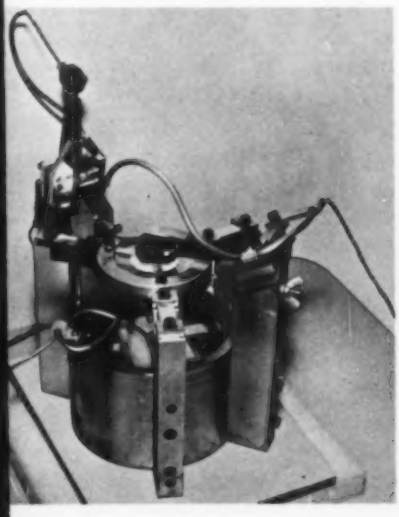
ARTIFICIAL MASTOID, *developed at Beltone Research Labs, is an electromechanical model of human skin and bone parts that affect hearing. The model is a useful experimental device for calibrating hearing aids and audiometers. It simulates the effects of skin and bone damping, resilience, and mass.*

this. Sounds, probably—and we need to know much more about this. When we do, we may be able to use this information to help us defend ourselves against insect pests without the indiscriminate slaughter of good and evil alike—even slaughter of birds and other useful wild life—by nonselective insecticides. For sound signals are usually specific and have meaning only to the species concerned, thus giving precision to our efforts against target species.

Research has shown that the mammalian ear is a remarkably sensitive instrument. Many studies are in progress on mammalian hearing, mostly designed to help us to understand human hearing. Studies on bats, porpoises, and rats and mice, however, have other objectives. With the first two mammals, their echolocating systems have led to interest in the necessary sensitivity of the receiving and sorting equipment. Information on so compact a system as these animals have might lead to methods for miniaturizing our sonar equipment and thus extend its usefulness. In the case of rodents, their extreme sensitivity and intense reactions to high-frequency sounds have led to studies on their range of sensitivity. Sounds that are ultrasonic for man can be heard by many other mammals. The fact that rodents can hear well above the highest frequency that man can may mean that ultrasonic sound—silence for man—could be used for rodent control.

Destruction by sound and ultrasound

Earlier workers on the effects of sounds on living things usually worked with very high intensity underwater sounds or ultrasounds. Bacteria, yeasts, blood cells, seeds, even frogs and fish were immersed in these intense sound baths. With even short exposures, the microorganisms were destroyed, suggesting that ultrasonics could be used for sterilization and pasteurization. Mutations and other damage to plants and animals were reported. If lower intensities or shorter exposure times were used, bacteria or yeasts could be dispersed in liquids, speeding up decomposition or fermentation. Some seeds germinated better after light ultrasonic treatment. While all these effects suggested obvious practical applications, only recently have prices of equipment declined to the level of possible economic practicability for many of these. Earlier workers, while realizing the possible implications, were more intrigued by discovering how the sounds did what they did. Were the results due to mechanical agitation, or heat produced by absorption of the sound, or bombardment by micro-bubbles? Studies still continue.



The effects of very high-intensity, airborne sounds on animals have only recently been studied. In our own experiments, mice were killed in less than 30 seconds by subjecting them to sonic or ultrasonic sounds at sound pressures of 1 watt per sq. cm. Insects were destroyed in a few seconds in these sound fields. Unfortunately, killing of pests by this method is not economically feasible, for the production of such sounds requires very expensive equipment, and, if an animal could be caught and held in the sound field, it could be destroyed by other means much more cheaply.

Cooking with sound

Animals are destroyed or injured according to the *intensity* of the sound. Intensity levels are commonly measured in decibels (db), and we shall use that scale—a logarithmic one. In the audible frequencies, at an intensity of 90–100 db (corresponding with the sound of a noisy street intersection, for instance), man has trouble communicating by voice with others but otherwise suffers no outward effects. The mouse, on the other hand, may be so excited by sound at the same levels (and frequencies above 5000 cps) that it is thrown into a running fit and convulsion which may result in death.

The same frequencies at about 130 db (comparable with sound produced

by a pneumatic hammer on a boiler), cause damage to our ears and to those of the mice and pain is felt. At 145–155 db (about 100 times more intense), the mouse begins to heat, and we can feel some warming of our skin. By placing thermocouples in the mouse's fur, we find that the fur absorbs the sound and thus produces heat. Fur temperatures of mice in the sound field can be as high as 90° C. The mouse can be literally cooked in its fur by these high-energy sounds. Man, lacking fur, reflects most of the sound and heats only slowly. Man is also larger and takes much more heat to raise his body temperature. When we shave the mice, they too absorb so little that they heat only slightly. But there is a limit, and, at 160–165 db, the mice are burned and so are our fingers.

Sound is energy. As our industrial and military machines increase in energy output, they increase in sound output, and the problems this creates are now being actively investigated. The levels of tolerance are by no means certain.

State of the bio-engineering art

What is being done right now in biological acoustics? From the standpoint of fundamental research, a number of persons are interested in mammals and birds. A few are working actively with frogs, toads, and fish. Very few are working on insects, when compared with the great numbers of persons studying other facets of insect life. And even fewer are studying all the other animals. So far, attempts to apply present knowledge for practical purposes have been made by only a handful of persons. Why? For one thing, few practical biologists are trained to handle the ideas and equipment needed. But, much more important, those who are so trained are more interested in basic studies on animals.

Let us take an example from our own work. In 1953, we found that broadcasting the recorded distress call of the European starling to roosting flocks could cause them to leave the roosts, and, if treatments were carried out correctly and persistently, to stay away for long times. Recent studies in Germany and in Holland have shown that this method is successful with starlings feeding on fruits. More recently, we have found that gulls and crows can be attracted or driven away.

When a new insecticide is discovered, the chemist can be assured that a corps of economic entomologists, trained in chemical insect control and planned testing, will take it and find its value, its weaknesses, and the factors influencing its actions. We in the United States need just such persons to test acoustical methods for control of pests. Germany and France have laboratories with staffs interested in this. We do not.

But let's extend this further. The possibilities for biological manipulation of our environment are tremendous, and we can see their extent only dimly. For full practical realization, the basic discoveries of biology will have to be applied to the solutions of specific problems by persons trained in biological thinking, but with a bent toward the practical. In short, we shall need *biological engineers*. The possibilities opening before us for genetic, biochemical, biophysical, and evolutionary manipulation of man, his fellow living creatures, and his environment justify far wider horizons for practical biology.

By further study, we may produce a small electric sound producer that can hold off insects we don't want, such as mosquitoes, and, with the shift of a dial, call in birds or fish we do want. But the use of sounds to influence the lives of animals and possibly plants for our and their benefit is only one of the many future developments which current research with living things can bring. If the basic information already on hand and that still to come is to be put efficiently to practical use, we shall need engineers who are trained in the life sciences as they now are trained in the physical. ■

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17B

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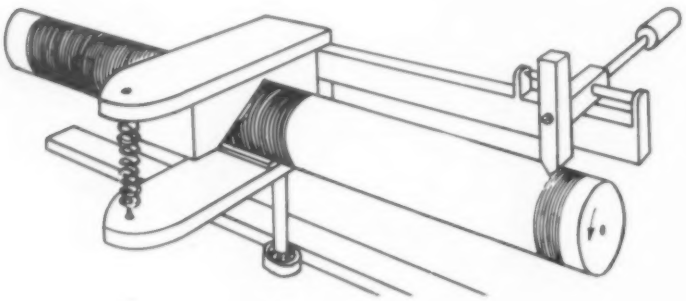
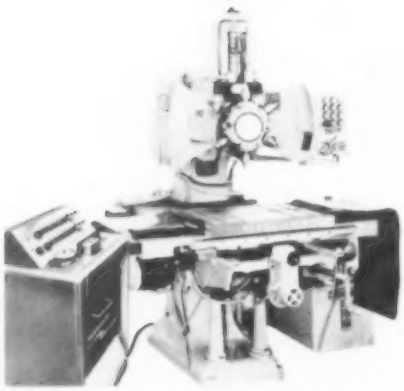
MOIRÉ FRINGES *provide a means for using diffraction gratings in dimensional-control systems. The vertical lines (above) are called moiré because of their resemblance to patterns produced by overlapping two layers of watered silk. The pattern above was made by Industrial Research by superimposing two ruled sheets, then rotating one slightly. For further rotation, more fringes are formed and the lines move closer together. Movement of the moiré patterns resulting from relative rotation or translation of the gratings can be detected by a light and photocell system. If one grating is moved up or down a small distance, the dark lines move horizontally by a much greater amount, thus providing sensitivity. Lord Rayleigh first observed the phenomenon.*



an optical method for dimensional measurement



NEARLY PERFECT THREADS *from imperfect ones can be made by the technique shown above. The imperfect thread has a cork pad clamped against it. As the bar rotates, the pad averages errors, and the new thread cut at right is nearly perfect. Gratings are made from this thread. At left is a tape-controlled machine-positioning unit with a diffraction-grating measuring system. Accuracy is ± 0.0005 inch. (Made by Ferranti, marketed by Bendix)*

INFRARED SPECTROMETER *with a Merton grating is used for studying optical spectra. Such instruments are needed by industry and research laboratories for analyses of mixtures.*

NEARLY 300 YEARS AGO, soon after the formation of the Royal Society *(The Royal Society of London for the Promotion of Natural Knowledge, founded by King Charles II and now celebrating its 300th anniversary)*, a newly elected Fellow communicated a paper on the composite nature of light. He was a young Cambridge don, Isaac Newton, and his method of splitting light into its colored components—the spectrum—was to pass it through a glass prism.

The special importance of New-

Dr. Sayce originally was a chemist, and until the war he lectured on chemistry at King's College, University of Durham. During the war he worked on camouflage and became assistant director of physical research at the Admiralty. Dr. Sayce joined the National Physical Laboratory in 1948 because during peacetime he preferred work of importance to industry. In 1958 he was made a Companion of the British Empire.

by **Dr. L. A. Sayce,** *superintendent of light, National Physical Laboratory, London*

ton's discovery remained latent for 150 years, but in due course became the foundation of "spectroscopy"—the study of spectra—which led to an understanding of molecular structure.

Newton's method of analyzing light still is used widely, but for many purposes it has been superseded by a more powerful method made possible by replacing his reflecting prism with a "diffraction grating."

An exacting hobby

A "diffraction grating" consists simply of a suitable surface scored with a very large number of closely spaced parallel grooves. Yet the making of gratings has proved one of the most difficult tasks in practical physics. It has been the exacting hobby of amateurs and the goal of at least one Nobel prizeman. Even now, after more than 100 years of endeavor, spectroscopists and astronomers are not fully satisfied with their results.

The difficulty lies in the exceedingly high accuracy required in the ruling process: a grating may be 10 inches wide with many thousands of grooves to every inch. Yet all these grooves should be spaced evenly to an accuracy of a millionth of an inch (100 times more accurate than the demands of precision engineering).

Thus, an essentially simple problem can be approached only by strictest attention to design of the ruling machine, or engine, the nature and surface of the work-piece to be ruled, and the highly-polished diamond tool that is used.

Most gratings in use today have been made by the method devised 80 years ago by Prof. Rowland, of Johns Hopkins University. Using a refined form of the engineer's shaping machine, he ruled a grating by successive strokes of a tool moving backwards and forwards in a straight line, while after each stroke the work-piece was moved sideways by means of a screw.

At the end of World War II there was an urgent demand for more and better diffraction gratings which the few Rowland-type engines in the world were unable to meet. It was opportune, therefore, that just at that time, Sir Thomas Merton, treasurer of the Royal Society, proposed an entirely new method which offered an unlimited number of gratings at a considerably lower cost than older processes.

Since then, his methods have been developed at Britain's National Physical Laboratory (NPL), near London, and have formed the basis of some far-reaching methods of accurate measurement and machine-tool control.

Cylindrical gratings

A Merton-NPL grating is not ruled on a flat or concave surface, as in the older Rowland process, but is generated on an optically polished metal cylinder in the form of a very fine helix, or screw-thread, by means of a diamond knife-edge. A special screw-cutting lathe is used in which the lead screw is geared down to revolve extremely slowly. According to the gear ratio used, the resulting screw-thread may be of any pitch between 100 and 30,000 turns per inch.

But even the best of lathes is imperfect, and errors in gearing, lead-screw, and its bearings cause the pitch of the helix to vary slightly in a regular periodic fashion—turns of the screw-thread being alternately a little too close together and then a little too far apart.

These variations are too small to matter in ordinary screws. But they must be eliminated somehow; otherwise spectra formed by the finished grating will be marred by confusing "ghost" lines.

Merton's method of doing this was both simple and elegant and is shown in the diagram below. The fine lathe-cut helix possessing its undesirable errors is shown at the left-hand end of the metal bar.

This helix is embraced by a "Merton nut" lined with three strips of cork pressed firmly into the fine grooves of the helix. The "nut" is constrained from rotation and is attached to a diamond tool acting upon the right-hand end of the bar. If now the bar is rotated, the nut travels gradually along the left-hand imperfect helix, and a similar helix is scribed by the tool at the right-hand end.

The device is rather similar to the chasing lathe widely used by engineers, but the difference lies in the ability of the Merton nut to average errors of the helix which it embraces. Consequently, the right-hand helix is found to be a very great improvement and entirely free from periodic errors.

A plastic copy

Having thus produced a perfected helical diffraction grating, the next task was to make an accurate copy of its grooves upon a perfectly flat surface. The helix first is coated uniformly with a syrupy solution of polystyrene, a plastic which hardens to a thin tough film.

This film, or "pellicle," is slit lengthwise and peeled off the metal bar. It bears on its inner surface an exact copy of the helix, and this inner surface then is laid down upon a thin, perfectly uniform layer of soft, moist gelatine that has been cast upon a flat glass surface.

It is allowed to remain there, undisturbed and at a uniform temperature, for about a week. During this time, the gelatine slowly dries through the overlying pellicle, and as it dries it hardens. So, after the drying time has elapsed, the plastic pellicle can be stripped off, leaving a flattened-out copy of the helix per-

manently molded upon the hardened gelatine surface.

From this flat gelatine copy it is a simple matter to mold a large number of glass-backed plastic copies. These are the finished diffraction gratings, though they require a thin layer of evaporated aluminum for most of their spectroscopic uses.

The plentiful supply of inexpensive Merton gratings made available by this process has proved very useful to scientific workers both in Britain and other countries, and it also has stimulated the industrial use of spectroscopy.

Atoms via spectroscopy

Knowledge of the "spectrum" has grown immensely since Newton's day, when it consisted only of visible wavelengths. It is now known that this visual spectrum is a very small part of a vast gamut of wavelengths, a mere octave in a tremendous scale of radiations.

Ultraviolet, or radiation having shorter wavelengths than visible light, has told us much of what we know about the make-up of the different kinds of atoms. Infrared, or radiation having longer wavelengths than visible light, makes possible the identification of molecules. It is in the field of infrared applied to molecular spectroscopy that Merton gratings have proved especially helpful, and several British firms are using them to make industrial instruments.

Another use for diffraction gratings has been developed at the National Physical Laboratory recently. We have seen that a grating consists of a large number of parallel grooves spaced with extreme regularity. They thus possess the attributes of very accurate measuring scales.

When gratings were expensive products of older processes, their use for measuring was impracticable, nor could they be adapted to the sizes and shapes required for engineering purposes. But the Merton process has made it possible to produce accurate gratings of considerable length quite cheaply.

Moiré measurement . . .

Provision of the gratings themselves is only half the problem; it is just as important to find out how to use them. They are quite different from ordinary coarse scales in which the separate divisions can be marked by a succession of long and short lines and by numbers. In a grating, with many thousands of divisions in each inch, it would be difficult enough to observe single divisions, and impossible to label each one.

Fortunately a method has been developed which makes this task unnecessary. It depends upon an observation made many years ago by Lord Rayleigh that two identical gratings placed one over the other with their rulings nearly, but not quite, parallel give rise to a pattern of straight lines running at right-angles to the rulings.

These lines have become known as "moiré fringes," or simply "moiré," because of their resemblance to similar patterns produced by overlapping two layers of fabric in moiré, or watered, silk.

The formation of moiré fringes by two very coarsely ruled gratings is illustrated below. If these were actual rulings on glass—and the short "index" grating 'A' were moved like the cursor of a slide-rule along the longer "measuring" grating 'B'—the horizontal fringes would be seen to move up or down. They would move up or down according to the direction of movement, and each fringe would take the place of its neighbor every time a ruling space had been traversed.

"Promotion wants a new product tomorrow, okay Murray?"

Further, if the index grating were covered by an opaque mask—from which a narrow horizontal slot had been cut—the area of the slot would be alternately light and dark as the "cursor" was moved. A photocell looking towards the slot would record each fringe as a change in electric current.

By an elaboration of this simple system, even the finest gratings can be used for measurement, and the method has several outstanding advantages. First, fringes observed by the photocell are produced by many intersections of the two gratings.

The resulting electrical signals therefore average out any local errors in spacing of the gratings. Second, the signals are well adapted for operating electronic counters and computers, or for comparing with other signals.

This new system of measurement is finding important applications both in research and industry. It is used extensively for measuring tracks of atomic particles revealed by "bubble chambers" of the nuclear physicist. It is becoming a tool of the astronomer in codifying the mass of information in stellar photographs, and it is shortening the tedious task of measuring complicated spectrum photographs.

. . . for controlling machinery

But moiré fringe measurement is likely to make its greatest contribution in the control of machinery. No machine is perfect, but if its imperfections could be observed by a perfect measuring system, the necessary corrections could be applied automatically by means of a servo system. This general principle of using diffraction gratings for measuring has been developed at the National Physical Laboratory, and can be applied to machine tools of all kinds. Its adoption in industry could lead to a higher general standard of accuracy.

And the use of gratings in machine-tools need not stop at correcting their mechanical imperfections. For instance, they have been applied very successfully by Ferranti Ltd. to a system where the human operator of a milling-machine is replaced by instructions conveyed to the machine by a magnetic tape.

The tape, prepared by an electronic computer from the necessary design information, is played back through a reading head adjoining the milling machine, and cuts out the work-piece in three dimensions simultaneously.

If, as it appears, diffraction gratings are becoming firmly established in engineering and measurement it is essential that industry should have an assured supply of gratings of the necessary accuracy. For this reason, the NPL is developing several new methods for making inexpensive gratings of all kinds.

Some of these are intended for measurements requiring the highest accuracy in measurement while others are for general engineering operations. Robust gratings of considerable length are required for such purposes, and these are being photo-etched on steel tape by Technicolor Co. from photographic master gratings prepared at the NPL.

The promise for availability of inexpensive gratings should do much to increase their application in new optical-mechanical systems for automatic control. ■

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I
BOOK REVIEWS
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The Kybernetics of Natural Systems, a Study of Patterns of Control, by D. & K. Stanley-Jones (Pergamon Press, New York, 1960, $6.50).

Kybernetics is a name given by the authors to studies of control systems in animals, to distinguish these studies from the more familiar cybernetics — coined by Ampere, used by Wiener, and now a dictionary word. The authors say they have not found it possible to use the concepts of information theory, channels of communication, entropy, and mathematical treatment to advantage in their biological studies. The reason is clear — they know little or nothing of these techniques.

Kybernetics may become one of those pseudo-scientific cults that achieves a degree of popularity for a time, then falls into unregreted disuse, along with positivism, technocracy, dianetics, ESP, and many others that we hope will be forgotten for the sake of scientific dignity.

However, kybernetics may become an important field for study. Freed from the handicap of an unsuitable vocabulary of terms, we could wish it luck.

Certainly, analogies need not be instructive — they are interesting for their own sake, and analogies even may lead to ideas that come from a more thorough understanding. But kybernetics is a backward step in the understanding of control in living or physical systems. Most of the examples would be understood more easily by leaving out the control-systems terms. The physiological terms should be completely adequate.

Consider the following discussion on mental stability as treated from the kybernetic viewpoint:

"Perhaps the most significant clue, and the most successful application, afforded by kybernetics is in the problem of no warning into an uncontrolled runaway. This risk lies inherent in every system that includes a positive feedback among its kybernetic controls. Always this positive feedback needs monitoring to keep it usefully within bounds, and always the risk will become actual when the monitoring system fails. It is difficult, often impossible, to detect a latent instability when all seems fair on the surface. With human material, perhaps it is safer always to assume its presence, to believe that every person has a threshold of tolerance, which when exceeded will break down into a temporary runaway such as a display of temper.

"With some, the starting-threshold is high (as with a ram-jet); these are the well-tempered people who preserve their equanimity. Others have a low threshold, or even none at all. Their pose in life is metastable, like a cone standing on its point, or (as a better illustration of an accelerated runaway) like a ball balanced on top of a globe. These unhappy folk can only keep going with much external help to maintain their stability; they are constitutionally unfitted to face life on their unaided own."

All of this is true for complex physical systems or for people, but has kybernetics added anything? Sometimes it confuses:

"The kybernetic pattern of sphincter-control (muscle-control) exhibits the reciprocal give and take which is the essence of balanced polarity. The dynamic aspect, the orthosympathetic, is subject to control by the parasympathetic. The latter is invariable structured on negative or stabilizing feedback. The former is potentially runaway; so long as it is monitored by the controlling and stabilizing system, tranquility is preserved. At times, however, the parasympathetic loses its dominance, the orthosympathetic gains the ascendant, and the sphincters, now unmonitored, close tightly in spasm: a runaway to maximum as regards the sphincters, but to zero when looked at from the viewpoint of the organ of the body as a whole. . . ."

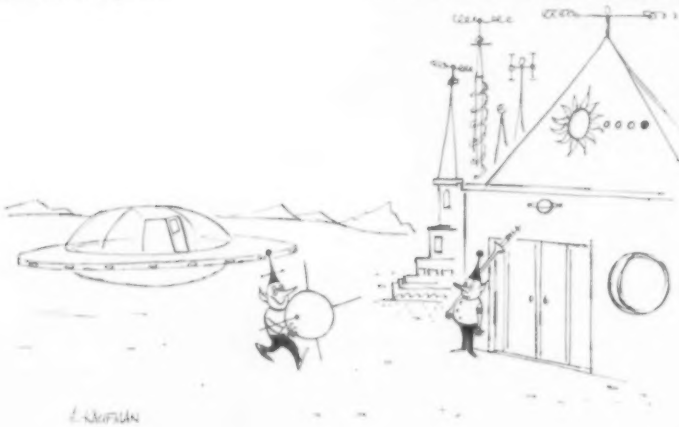
Aside from the unsuccessful application of a control-system vocabulary, this book gives a wealth of interesting information about animal-sensing devices, organization of nervous systems, and effects of disorder or disease on behavior of jellyfish, anemones, mussels, worms, locusts, cockroaches, lampreys, fish, and mammals. In each example the significance of kybernetic principles is discussed.

"Kybernetics of Human Society" is the title of the last chapter, a discussion of kybernetics in sociology, in history, and in war. Consider this interesting capability:

> "The specific contribution that kybernetics can make to the sociology of war is twofold. It can make a prediction as to its ultimate outcome, based on analogy with every other known instance of runaway refection; and it can study those restoring forces based on negative feedback which are necessary for stability, and which have failed in their monitoring duties at the outbreak of war."

For war problems, you can try kybernetics if you want to, but I'm going to look for something else.

—H. L. Garbarino
I•R technical director



Automatic Translation, D. Yu. Panov, translated from Russian by R. Kirsch (Pergamon Press, New York, 1960, $4.50).

This slim book (73 pages) is the translation of a second edition of a work which appeared originally in the USSR in 1956. The second edition has been enlarged to "give information on some new results."

Although recent work in Chinese-to-Russian translation is described, the added material does little more than indicate several problem areas in automatic translation — the need for semantic as well as syntactic analysis, the investigation of a so-called "information language" to summarize the contents of an article, the analysis of style and problems of literary editing, and the creation of an intermediate language for multi-language-to-multi-language translation. References cited are limited to work done in the U.S. and England before 1956.

Experiments in English-to-Russian translation performed on the BESM Computer at the Institute of Precise Mechanics & Computing Techniques, of the USSR's Academy of Science, are described. The input and analysis of English text, the automatic dictionary, and synthesis and output of Russian translation are illustrated with several flow-charts and examples.

Of special interest to those who can read Russian are sample translations which were made using a dictionary of approximately 5,000 Russian and English words designed primarily for mathematic texts. One example is a valiant attempt at an extract from Dickens' *David Copperfield*.

This book must be considered as a survey of automatic translation in the Soviet Union, rather than a definitive work in the field.

—Benjamin Mittman
Armour Research Foundation

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Present day decisions at the highest level of military command require a range and precision of communication and information processing beyond that conceivable in the past. Probably the greatest single new influence on the requirements for the decision-making process is the sharp reduction in reaction time which results from the introduction of the ballistic missile.

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(For values of R F & L as specified. For values of E ranging from 100 to 300 in increments of 50. For values of C ranging from .00002 to .000021 in increments of .0000001)

COMPLETE ALGO PROGRAM:

```
BEGIN ⓢ
R = 10 ⓢ
F = 60 ⓢ
L = .2 ⓢ
FOR E = 100(50)300 BEGIN ⓢ
FOR C = .00002(.0000001).000021 BEGIN ⓢ
I = E/SQRT(R ↑ 2 + (6.2832 * F * L — (1/(6.2832 * F * C))) ↑ 2) ⓢ
PRINT (FL) = E ⓢ
PRINT (FL) = C ⓢ
PRINT (FL) = I ⓢ
```

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RESEARCH

TRENDLETTER

Oct-Nov, 1960

Dear Sir:

The sound and ultrasound industry is finding new applications for its products and techniques almost daily. In the special section of this issue, beginning on page 45, I·R has given a broad view of the state-of-the-art in sound, and in future issues of Industrial research you can expect to see more about this interesting field. (Also see Ultra- and Hypersonics, I·R, April-May, 1960, page 30.)

For example, an application we had not heard of before is the use of sound to grade and mark lumber automatically, using a device developed by Reed Research Inc., 1048 Potomac St., NW, Washington 6, D.C. The instrument transmits acoustic energy through low-density materials such as concrete, plastic, and rubber, as well as wood. It makes an x-ray type picture of the sound waves on special paper. A change in transmitted energy represents a flaw.

Dynamic Sound Inc., 15235 Lorain Av., Cleveland 11, claims an ultrasonic instrument can clear a building of rats within 72 hours. The company suggests a time-clock mechanism to schedule broadcasting hours, and the use of poisons in rat exits so rats will poison themselves as they leave, and then die elsewhere.

A new sonic device is said to be capable of measuring the thrust of jet engines, and thus could replace complex instrumentation. Operation of the instrument is based on a definite relationship between jet sound power and jet thrust. The unit has been proven out on Boeing 707s, according to Industrial Acoustics Co. Inc., 341 Jackson Av., New York 54.

At the AEC's Hanford, Wash. plant, operated by the General Electric Co., sound is being used to pack powdered materials into nuclear-reactor fuel containers. The technique, using a 24,000-watt amplifier, is said to compact the powder to more than 90% of the density theoretically possible, and is fast, simple, and flexible. Tubes up to eight feet long are filled and packed in about three minutes.

New super-dense ceramics for sonar, ultrasonic processing, and electronic components are being produced by Gulton Industries Inc., 212 Durham Av., Metuchen, N. J. Radical improvement claimed is the result of new pressure-firing techniques suitable for both ferroelectric and piezoelectric ceramics. Also larger single-piece ceramic units now are possible -- discs up to 20 inches in diameter.

From Monsanto Chemical Co's Plastics Div., Springfield, Mass., comes a new sound-insulating safety glass. It consists of thin transparent panels of laminated polyvinyl butyral plastic sheet, and is particularly effective for frequencies of 1,000 to 4,000 cycles per second.

light

A new-type, experimental light source built by Duro-Test Corp., North Bergen, N. J., is being tested by the U.S. Army Engineer Research & Development Labs, Fort Belvoir, Va. The new source is a low-voltage, high pressure, multi-cathode xenon light. Xenon in a light is not new, but this is said to be the first multi-cathode xenon unit. The light can be used to give greater illumination over a wider area than conventional lights.

Flat, rectangular, fluorescent lamps will be available soon according to Westinghouse Electric Corp., Bloomfield, N. J. The light-producing arc travels through a maze of passages sealed in a thin glass block about an inch and a half thick. Plans are made to produce a light one foot square, rated 40 to 50 watts. Expected uses for the light plates are in shelf lighting and displays.

General Electric Co., Cleveland 12, soon will introduce a thin, flexible, electroluminescent panel claimed to be five times brighter than any now available. The flexible panels will be 30-thousandths of an inch thick, with areas as small as one square inch.

human factors

A package of clinical instruments to record body responses of a pilot during vertical motion tests has been developed for the Air Force by Armour Research Foundation. Included is an automatic camera to capture facial expressions. The console instrument records heart sounds, heart rate, blood pressure, respiration rate, electrocardiogram, blood oxygen content, and skin resistance.

materials

Natural rubber latex can be custom tailored for a wide variety of finished products by exposing it to radiation at the plantation, according to Goodyear Tire & Rubber Co., Akron 16, Ohio. Radiation with a suitable source, such as cobalt-60, initiates the formation of cross-linkages within the polymer, resulting in increased stiffness and strength. Irradiation also has been found to improve the storage properties of natural latex.

The Norton Co., Worcester 6, Mass., now is supplying boride, carbide, nitride, and oxide powders for use in plasma-arc spraying equipment. Available plasma spray units have extended the possible choice of materials that can be applied as coatings, because of the higher temperatures possible with plasma-arc equipment.

A new glass with extremely low natural radioactivity, less than 6% of comparable glasses, has been developed by Corning Glass Works, Corning, N.Y. The glass will be used to make bulbs, headers, and other components for photomultiplier tubes in radiation-measuring equipment. Such equipment measures radiation in humans, the atmosphere, foods, and clothing.

Promising high-temperature rocket materials -- high-density, super-graphites, are being produced by National Carbon Co., Division of

Union Carbide Corp., 100 E. 42nd St., New York 17. The material is said to have two to three times the high-temperature strength of conventional graphites, being usable at temperatures as high as 5500° F. The properties are the result of crystal alignment and internal grain structure of the materials.

chemistry

Certain organic chemicals behave like carbon black in protecting polyethylene from thermal degradation, according to Bell Telephone Labs, Murray Hill, N. J. The materials are hydrocarbons used with compounds containing sulfur. The hydrocarbons inhibit oxidation of the polyethylene.

Dearborn Chemical Co., Merchandise Mart Plaza, Chicago 54, has developed some new biocides for reducing bacteria in industrial cooling water. Bacteria can result in corrosion and slime-like algae. Major feature of the chemicals is their compatability with other water-treating agents and impurities in the cooling water.

Plastic-coated fertilizer capsules may be used on future crops. This would be a way to spread fertilizer effects over a longer time as needed throughout the season. Tests are being conducted by the College of Agriculture at the University of Wisconsin, Madison 6.

electronics

Rare earth compounds make possible a breakthrough in thermoelectric materials for energy conversion. (See The Abundant Rare Earths, I·R, Aug-Sept, 1960.) Gadolinium selenide prepared under specific conditions has a thermoelectric figure of merit three times as high as the best materials yet known, and will operate at temperatures up to 1500° C., according to Nuclear Corp. of America, P. O. Box 431, Burbank, Calif. Gadolinium selenide also shows promise as a p-type semiconductor for high temperature use. Gadolinium, one of the 16 rare-earth elements, is a possible control-rod material for nuclear reactors. Further investigations on this material may place U.S. industry ahead in direct conversion of heat to electricity and in refrigerating units.

A broad-band communication system that receives and transmits intelligent noise or static is being developed and tested by GE's Heavy Military Electronics Dept., Court St., Syracuse, N. Y. The system is based on a radically new and different approach from the conventional military communications technique, in which each transmitter and receiver is allocated a specific narrow bandwidth to avoid interference. In broad-band communications, the transmission bandwidth is many times larger than the intelligence bandwidth, or signal being relayed. For military communications, broadband techniques provide security against jamming (because of the tremendous amounts of power required to interfere with the transmitted signal), transmission security (because the average power is spread over a wide bandwidth making the signal extremely difficult to detect), and message security (because it can be made very difficult for an unauthorized listener to understand what's being transmitted).

A cesium-cell thermionic converter, which contains a nuclear fuel element made of uranium carbide and zirconium carbide, has produced

90 watts of electric power directly from the heat of nuclear fission in a series of operating tests conducted at the General Atomic Div. of General Dynamics Corp., P. O. Box 608, San Diego, Calif. (See photograph No. 1.)

An all-electronic alpha-numeric recognition device for identifying typed or printed envelope addresses is being developed by Philco Corp's Research Div., Tioga and "C" Streets, Philadelphia 34, for the U.S. Post Office Dept. The machine will be integrated with letter-sorting machines developed by the Post Office Dept. to further the automation of mail-handling in post offices. Electronic-scanning techniques will be used to locate and sort as many as 50 different addresses at the rate of 1000 alpha-numeric characters per second.

A tiny, ferrite magnetic core, doughnut-shaped and no larger than the period at the end of this sentence, has been developed by RCA, 30 Rockefeller Plaza, New York 20, N. Y. for digital computers. The significance of this new memory element is in its speed and size. When strung together in frames, stacked several deep and electrically wired, a memory unit about the size of a box of crackers can store 500,000 bits of information.

An undersea video tape recorder is aboard Seadragon, the U. S. Navy nuclear submarine, according to Minnesota Mining & Manufacturing Co., 900 Bush Avenue, St. Paul 6. Under-the-ice characteristics "seen" by externally installed TV cameras will be recorded and stored on magnetic video tape. The tape record of the under-ice "ceiling" will be a navigational aid for studying physiography of ice under the ice cap. The Navy will be able to determine by arrangement and density of ice formations whether a "path" lies ahead -- an important factor in finding safe submarine routes.

Alden Electronic & Impulse Recording Equipment Co. Inc., Westboro, Mass., is developing equipment to produce a composite weather map of the entire United States within a few minutes, using more than 100 radar photographs taken simultaneously, then combined and transmitted over a nation-wide facsimile network.

The use of power transistors at two to three times previously achievable ratings is possible with a new modular aluminum heat sink introduced by Astro Dynamics Inc., 200 Sixth St., Cambridge 42, Mass. A high-pressure, fin-assembly process produces a strong metal-to-metal bond and extremely high thermal conductivity between transistor and fins.

space

Payloads of space and orbital vehicles can be doubled as the result of a turbo-pump-fed rocket engine using liquid fluorine and liquid hydrogen as propellants, according to Bell Aerosystems Co., Buffalo 5, N. Y. Three hundred rocket firing tests were made using liquid hydrazine and hydrazine blends (instead of liquid hydrogen) as the fuel. Size and weight reductions of rocket engines without sacrificing performance are possible because fluorine is the most powerful of all oxidizing agents.

1

2

3

A new means to detect satellites is under development by Electro-Optical Systems Inc., 125 N. Vinedo Av., Pasadena, Calif. The system consists of a balloon-borne telescope that scans the sky and a telemetering link to the ground. (See drawing No. **2.**)

now available:

Lindly & Co. Inc., Mineola, N. Y., has a device to detect, count, and indicate yarn imperfections automatically. Sensitivity to defects of one-thousandths of an inch is claimed.

A motor smaller than the head of a thumbtack is made by The A. W. Haydon Co., Waterbury, Conn., for use in timing equipment. The motor weighs one-ninth ounce, and is rated 0.0005 ounce-inches torque.

Resistance-type thermometers for surface temperature measurements to 2,000° F. are available from Arthur C. Ruge Associates Inc., Hudson, N. H. The units consist of a platinum wire grid encapsulated in aluminum oxide, and can be attached by cementing, bolting, or welding.

Fuel-carrying "tire tanks" by Goodyear Tire & Rubber Co., Akron 16, Ohio, have been developed for the Army's Transportation Research Command. Towable by almost any vehicle, their construction gives them low ground pressure over a wide contact area.

The Delcon Corp., Palo Alto, Calif., has developed a "scramble" security telephone device for business, industry, and law enforcement. For use with the standard telephone system, it weighs 27 ounces, and requires no wires or other connections between the "scrambler" and the telephone handset. (See photograph No. **3.**)

Infrared Industries Inc., Waltham, Mass., has a new line of six highly-stable, black-body radiant energy sources for precision calibration of infrared instruments available in several temperature ranges from 50° C. to 1000° C.

A self-contained, portable electric furnace is available from Pereny Equipment Co. Inc., Chambers & Pereco Sts., Columbus 12, Ohio. The furnace is suitable for temperature requirements up to 2900° F.

A copying machine developed by Haloid Xerox Inc., 8-1824 Haloid St., Rochester 3, N. Y., turns out engineering drawings up to 18 by 24 inches from microfilm frames mounted in die-cut apertures of data-processing cards.

new processes

Dynametrics Corp., Northwest Industrial Park, Burlington, Mass., has announced a batching system using binary techniques to improve weighing efficiency and reliability in applications involving the formation of materials by automatic batching.

Pressure vessels having very high strength-to-weight ratios have been produced, using resin-filament reinforcing wound onto the vessel, by Thompson-Ramo-Wooldridge Inc., 23555 Euclid Av., Cleveland 17. (See photograph No. 4.)

4

5

Fused silica casts for brazing complex contoured stainless steel honeycomb panels have been tested successfully at Boeing Airplane Co.'s Wichita, Kansas Division. In most cases, the new concept will permit elimination of the much costlier use of machined graphite fixtures, with which only the simplest contours have been possible so far. (See photograph No. 5.)

The Farrington Mfg. Co., Needham Heights 94, Mass., has introduced a system for recording production data. Machine operating times, down times, and the causes for down times automatically are recorded audio-visually on a special graph and on a tape recorder. For use by production control supervisors in planning work schedules.

The National Bureau of Standards, Washington, D. C., has developed a method for producing nickel-aluminum alloy coatings capable of protecting metals from oxidation at temperatures up to 1000° C. NBS also has developed a rapid, simple method of determining minute amounts of aldehyde in the air. Method involves the absorption of small quantities of aldehyde, ordinarily too widely dispersed to measure, onto the surface of silica gel. Analysis of aldehyde concentration provides a useful index of the amount of atmospheric exhaust fumes converted to smog.

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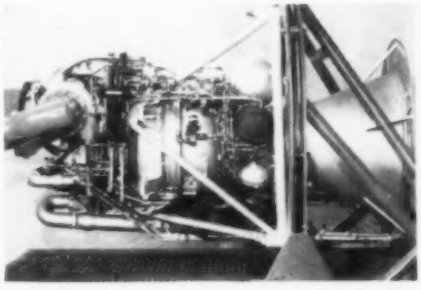
Engineers of Reaction Motors Division of Thiokol Chemical Corporation specified an accumulator diaphragm of Silastic LS for the X-15's XLR-99 engine. The accumulator provides oil at a constant pressure to the lube oil pump. Gaseous nitrogen under pressure is the source of stored energy, and is separated from 4-11V Halocarbon oil by the Silastic LS.

Here are diaphragm requirements the designers established as essential: An elastomer flexible from —80 to 200 F (Silastic LS maintains its flexibility from —80 to 500 F); compatible with the lube oil at low and elevated temperatures (Silastic LS has little swell or change in durometer readings after immersion in many hot oils, fuels and some hydraulic fluids); will not contaminate lube oil (Silastic LS has no plasticizers or additives which can contaminate by leaching).

Silastic LS... the only elastomer to meet all these requirements... helps the X-15 as it knocks on the door to outer space.

Shown below is the XLR-99 rocket engine. The lube oil accumulator is the light weight type... made possible by the diaphragm of Silastic LS... instead of the heavy, bulky piston type. Parts of Silastic can be engineered to meet your specific needs by your rubber fabricator.



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